

DESIGN FOR ESCAPE FROM FIRE

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Abstract

Providing safe means of escape from fire requires more than just having a designated route out of a building. It is shown that the conditions relating to the fire, the building characteristics and the number, distribution and activities of the occupants all have a bearing on the requirements for escape.

Safe escape from fire in buildings is required by the New Zealand Building Act.

The Building Industry Authority (BIA) Handbook of Acceptable Solutions provides a set of prescriptive design rules for the means of escape from buildings. Compliance with these rules is deemed to comply with the legal requirements of the Building Act.

The necessity of considering the BIA Acceptable Solutions as an integrated solution is discussed. The Building Act allows for the specific design of means of escape where the Acceptable Solutions are inappropriate or where an alternative solution is desired. Alternative solutions must show, to the approval of the Territorial Authority, that compliance with the requirements of the Building Act for safe escape is provided.

The action of the occupants in the act of escape from an evolving fire requires consideration of both time and space; the solution becomes an exercise in four dimensions. These aspects are discussed in some detail, and design criteria. The necessity of relating the development of a fire and the products of combustion with the progression of occupants escaping to a place of safety is demonstrated.

It is shown that design for safe means of escape may be effected by a variety of inter-related factors. Variation from the BIA Acceptable Solutions requires consideration of all aspects of the design process. The design is a specific solution and must be at least as effective and efficient as the requirements of the Building Act.

The design of safe means of escape requires construction of 'time lines' for the fire, including tenability conditions, and the egress movement of occupants.

The necessity to include margins for safety and the reliability of systems is briefly discussed.

This report shows the steps necessary to provide safe means of escape for compliance with the Building Act.

Comparison is made of occupancy densities as found in NZ, as noted in design guides and overseas reference literature.

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NOMENCLATURE

Abbreviations

BA	Building Act (1991)
BIA	Building Industry Authority
FLED	Fire Load Energy Density
IQP	Independant Qualified Person
NZFS	New Zealand Fire Service
OD	Optical Density
RTI	Response Time Index

Symbols

B	boundary layer width (m)
C	mass concentration of smoke
D_o	occupant density- persons/sq.m
D_s	stairway occupant density - persons/sq.m
DL	optical density/unit length
e_a	efficiency related to ascending stairs
e_d	efficiency related to elderly, young or unfamiliarity
e_f	total efficiency factor
e_r	efficiency related to riser height
e_t	efficiency related to tread width
F_c	calculated flow - persons/minute/m
F_s	specific flow - persons/minute/metre
F_{sm}	Max specific flow - persons/minute/metre
G	going dimension on stairs
h	floor to floor height
K	extinction coefficient factor
k	absorption coefficient of smoke
k_t	travel factor : 84 for horizontal
k_t	travel factor : $51.8 \cdot (G/R)^{0.5}$ for vertical
L	path length of optical beam
L_a	length of travel on landing
L_s	length of stairs - along the slope
l	intensity of light with smoke
l_o	intensity of light without smoke
N	total number of occupants
P	persons/m
P_e	effective width/person (m)
R	stair riser dimension (mm)
S	travel velocity (m/min)
S_v	visibility distance (m)
T	stair tread dimension (mm)
t	travel time (sec)
t_a	time to activate alarm
t_d	time for detection (min)
t_{el}	elapsed time(min)
t_{ev}	evacuation time (min)
t_{fa}	time for fire service to arrive at scene (min)

t_{lh}	time to heat incapacitation (min)
t_{lt}	tenability time limit (min)
t_m	time of movement (min)
t_r	travel time (min)
t_r	response time before moving (min)
t_t	total travel time (min)
t_v	time to validate alarm (min)
W_e	effective width (m)
θ	slope of stairs or ramp

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Chapter 1. Introduction

1.1 Introduction

The design for safe means of escape from fire requires more than just designating a route to the outside from any internal space in a building. The passage to escape must allow the movement of all the likely occupants without their safety being compromised by the changing fire conditions along the route during the time required to reach safety.

1.2 Objectives

The objectives of this study are -

- * to describe the prescriptive rules of the NZ Building Industry Authority's Acceptable Solutions; and
- * to discuss factors affecting escape from fire; and
- * to propose a design procedure for safe escape from fire; and
- * to give occupancy data for some New Zealand retail and working occupancies.

1.3 Background

Safe Escape from fire in buildings is required by the New Zealand Building Act (NZG, 1996).

The Building Industry Authority Acceptable Solutions (NZ Building Industry Authority, 1995) provides a set of rules for the means of escape from buildings. Compliance with these rules is deemed to comply with the legal requirements of the Building Act.

The Building Act provides designers with the opportunity to provide alternative solutions to those of the Building Industry Authority. Compliance with the requirements of the Building Act and the Building Regulations (NZG, 1997) by the proposed solution must be demonstrated to the Territorial Authority. The Territorial Authority can accept a design if they have 'reasonable grounds' to believe that it meets these requirements.

In this report the measures required in law, by the Building Act and the Building Code are described. This is followed by a description of some of the conditions of the Building Industry Authority's (deemed to satisfy the Building Code) Acceptable Solutions. To put the design for safe escape into context it has been considered appropriate to consider -

- * the specific dangers of fires to occupants; and
- * information on the frequency of fires, causes, locations and fatalities in New Zealand.

Information on New Zealand conditions relating to establishing the numbers of occupants likely to be present and their abilities to escape are demonstrated in Chapter 4.

Escape to safety may be significantly affected by the presence and activation of detectors and alarms. A brief discussion of the role of these devices in the design for escape is included in Chapter 5.

The response of occupants to a fire involves consideration of the relationship of the individual occupant to the fire, the type of warning cue received and a range of physical and sociological factors. These factors require careful consideration of those responsible for the design of escape, because of the possible range of responses and are examined in Chapters 8, 9 and 10.

The evacuation process and the manual calculation of travel times on horizontal and vertical routes are demonstrated. Various computer based programs are identified, with some discussion of their relevance in Chapter 11.

To assist in the design of escape from a fire, notes are included for the assessment of the development of a fire and untenable conditions in a firecell.

New Zealand has a requirement under the Building Code for regular testing and maintenance of fire safety systems; and under the Fire Safety and Evacuation of Buildings Regulations (NZG, 1995) at least twice yearly evacuation drills are required from most premises. The effect of training on behaviour patterns and escape is discussed.

The Building Act sets out requirements for safety in a fire situation. This may rely upon the reliability of the safety systems and procedures. Discussion of a formalised and analytical approach to the reliability of safety systems is presented in Chapter 13.

1.4 Terminology

Unless expressly noted terms and definitions used in this study are consistent with the Building Act, Building Code and Acceptable Solutions. Refer also to the Nomenclature listing for abbreviations and symbols used in this report.

It must be noted that at the time of preparation of this report the Acceptable Solutions were last amended as at 1 Dec 1995, and are currently subject to revision. The Review Committee has not made available any data with respect to any of the aspects being considered.

Chapter 2. Acts and Regulations

2.1 Building Act Requirements for Means of Escape

In New Zealand legislative control of building is through the Building Act 1991. One of the principles of this act is that in the event of fire building occupants *"shall not be subject to injury or harm and that adjacent property should not be adversely affected."*

The First Schedule to the Building Regulations is known as The Building Code which expands on these principles.

The Building Regulations are effectively a set of rules prepared under the provisions provided in the Building Act. These rules have legal standing, without having been passed as an Act by Parliament.

2.2 NZ Building Code Requirements for Means of Escape

2.2.1 Code Objectives

The NZ Building Code (NZ Govt 1992) requires consideration of means of escape from all buildings and of other fire safety measures for all buildings except detached single dwellings that are not more than two storeys and are at least 1m from the property boundary.

With respect to Means of Escape the Building Code provides the following objective-

- "(a) Safeguard people from injury or illness from a fire while escaping to a safe place;*
- and*
- (b) facilitate fire rescue operations."*

This objective can be satisfied by functional requirements which are stated as -

Buildings shall be provided with escape routes which:

- "(a) Give people adequate time to reach a safe place without being overcome by the effects of fire, and*
- (b) Give fire service personnel adequate time to undertake rescue operations."*

This is expanded in more detail by the specification of performance requirements as follows:

"The number of open paths available to each person escaping to an exitway or final exit shall be appropriate to:

- (a) The travel distance,*
- (b) The number of occupants,*
- (c) The fire hazard, and*
- (d) The fire safety systems installed in the firecell.*

The number of exitways or final exits available to each person shall be appropriate to:

- (a) The open travel path distance,*

- (b) The building height,
- (c) The fire hazard, and
- (d) The fire safety systems installed in the building.

The escape routes shall be:

- (a) Of adequate size for the number of occupants,
- (b) Free of obstruction in the direction of escape,
- (c) Of length appropriate to the mobility of the people using them,
- (d) Resistant to the spread of fire as required by Clause C3 "Spread of Fire",
- (e) Easy to find as required by Clause F8 "Signs",
- (f) Provided with adequate illumination as required by Clause F6 "Lighting for Emergency", and
- (g) Easy and safe to use as required by Clause D1/3/3: Access Routes."

For Means of Escape all new buildings are required to comply with the Building Code. The Act also requires that -

- * *"buildings subject to alteration comply as nearly as reasonably practicable with the provisions of the building code as if it were a new building; (and to comply with other provisions of the building code to at least the same extent as before the alteration (S38))*
- * *where there is a change of use of a building it shall comply as nearly as reasonably practicable with the provisions of the building code as if it were a new building (S46)."*

Compliance with the Building Code is a legal obligation for building owners.

The NZ Building Industry Authority has produced Acceptable Solutions, compliance with which are deemed to satisfy the requirements of the Building Code.

It appears from the Acceptable Solutions that the prescribed requirements for Means of Escape are based upon the following philosophy and principles -

- * limitation of the time building occupants may be exposed to fire and combustion products (excessive exposure time may involve untenable conditions and consequently injury or death).
- * provision of alternative escape routes where a single route may result in excessive exposure time.

It must be noted that there are requirements for Means of Escape from single household dwellings - but they tend to be ignored in general design practice because other factors normally result in compliance with this aspect of the Acceptable Solutions.

2.2.2 Means of Escape - by Rules

Section C2 of the Acceptable Solutions provides a set of rules that apply the above concepts - and includes variations depending upon a range of conditions. A general description of the process follows.

Building Occupancy

The number of firecells in a building must be determined, and the purpose group (activities within the firecells) and number of occupants within each firecell determined.

Escape Routes

Escape routes for travel may fall into three categories: -

1. Open Travel Path (with routes with no alternative being called Dead End Open Path, and the overall route called the Total Open Path)
2. Protected Path
3. Safe Path.

Escape routes must end in or at a Safe Place.

Open Travel Paths provide for no protection by way of fire or smoke separation from the fire location.

A Dead End Open Path is the where there is no alternative open path route (normally at least 10m distant from any other route).

A Protected Path is a travel route that is separated from the potential fire area by smoke separating partitions or similar. A Safe Path is a travel path that is separated from the fire area by fire rated partitions or construction.

Escape from the compartment of fire origin commences on an Open Path and must end at a safe place, possibly via a Protected Path followed (possibly) by a Safe Path. The Acceptable Solutions limit the activities that may be undertaken in a Safe Path. Conditions are also given for the relationship of Safe Paths with lifts and car-parks.

Consideration must be given to the protection required for occupants, escaping from compartments not containing the fire, but who may need to travel past the fire.

Widths of Escape Routes

Tables in the Acceptable Solutions provide the widths of egress routes relating to the purpose group (commonly the lesser of 1000mm and 7mm/person for horizontal routes and 9mm/person for vertical travel routes). Conditions are provided for widths of doors and windows and the direction of opening of doors.

Lengths of Escape Routes

Permissible distances are provided for the various travel paths for the various purpose occupancy groups. It appears Dead End Open Path lengths have been shown, by both Barnett (1995) and Wade (1992), assuming travel speeds and mobility for the various purpose groups to be equivalent to the distance traveled in a time of 1 minute; and in 2.5 minutes for Total Open Path distances (see 10.3). The permissible maximum protected path distance has been set equivalent to the total open path. There are some restrictions on Safe Path distances, but safe paths may be concatenated (by accumulated entry into successive safe paths/firecells). It is noted that 2.5 minutes has been used for many years in the UK (Paul, 1995) on the basis of some trial evacuations. This has subsequently been shown to not be representative. Pauls notes that because the results have not been repeatable the continued reliance on this data may be dangerous.

Where detector or warning systems are installed these permissible Open Travel Path distances may be increased as follows -

*	heat detectors	15%
*	sprinklers	50%
*	smoke detectors	100%

Where the occupancy density is very low (0.05 persons/sq.m) the permissible open path distances may be increased by 100%.

Where more than one of these systems is installed a cumulative effect, with a maximum increase of 150%, is permitted of the basic permissible path lengths.

The rationale to the increases with respect to installed systems appears to be related to the early warning and/or control (in the event of sprinklers) in alerting occupants to danger and escape. The time or safety gained by this system has then been converted into an equivalent travel distance. For example - another 2.5 minutes for smoke detectors.

It is to be noted that although smoke detectors alert occupants sooner, sprinklers actively suppress the fire.

With very low occupancy numbers it appears likely that there -

- * will be no congestion with numbers escaping
- * may be larger distances or separations within the firecell.

There has been no commentary to justify or explain these increased distances within the firecells for low occupancy situations.

No increases are permitted to the basic Protected Path distances.

Vertical Safe Paths

Vertical Safe Paths (stairway shafts) are subject to several provisions.

Where occupants using a shaft travel both up and down to meet at a common egress level, the two paths require to be smoke separated. No reason is given for this condition.

Shafts over 25m tall require smoke separation at approximately mid-height. No reason is given for this condition.

It is assumed that in each instance the separation is to prevent the vertical smoke spread affecting those at upper levels - assuming that an alternative egress can then be entered. For buildings with electronic automatic locking of stair access doors, exit from a shaft may not be possible. If it is the intention that an alternative route is to be available for use, from that point, then further explanation is required in the Acceptable Solutions.

Single Escape Routes

Provision is made for single means of escape; ie no alternative escape route being required. Typically there are limits on the number and age of occupants using the route. Horizontal travel is limited to the permitted Dead End Open Path (until reaching either a Protected Path, a Safe Path or a Safe Place). For vertical Safe Paths the limit is typically four floors unless the building is sprinklered, then the limit is six floors.

Generally, except under the limited conditions for a single escape route, two or more independent routes are to be available. While not being explicit in the Acceptable Solutions it is generally assumed that only one of the independent routes has to comply with the escape route travel distances. This has been supported by an opinion from the Building Industry Authority. (BIA, 1993). The inference is that if one of the routes is affected by fire, then the independent alternative route is unlikely to also be effected, and therefore the distance and time are immaterial as evacuation is away from the dangerous area or condition. This assumption could be debated, but appears in the writer's opinion, to be generally reasonable.

Surface Finishes

Surface finishes may contribute to the danger from fire through either promoting the spread of flame and the development of smoke. Rapid spread of flame across an ignited surface (floor, wall or ceiling) may result in ignition of other objects and a significant extension of the fire area and size (in terms of heat release). Such rapid growth could result in either a reduction in the time available to escape or even surrounding the occupants with fire. It is noted by Purser (1995) that vinyls, subjected to fire, may produce quantities of chlorides at relatively low temperatures, and these may have serious incapacitating effects on occupants.

The smoke developed by the burning surface may be sufficient to effect visibility and/or may be toxic, so limiting the opportunity for safe escape by occupants. The Acceptable Solutions prescribes indices for spread of flame and smoke development (Spread of Flame Index and Smoke Developed Index respectively) for ranges of occupancy conditions.

Significant problems arise with -

- * uncontrolled on-going maintenance resulting in application of inappropriate surface finishes; and
- * determining the properties of an existing coating (and its ratings) in areas subject to alteration and also requiring compliance for Means of Escape.

2.2.3 General

Because the rules are meant to cover all situations they frequently can be found to be too conservative or to impose conditions that are on occasions considered by some designers to be excessive. There are other situations where matching the rules with the design situation is seen as not practicable; and in some instances doubts have also been raised as to whether the Acceptable Solutions always meet their objective in providing for safety of occupants.

Where a design does not fully comply with the Acceptable Solutions the designer must show compliance with the Building Code. The design rules set out in the Acceptable Solutions rely upon the inter-relation of many factors. Any variation automatically becomes an alternative solution for means of escape, and will necessitate showing that all the factors incorporated into the Means of Escape of the Acceptable Solutions are also considered within the design.

It is proposed in this study to present a procedure for the design of means of escape to comply with the code objectives and so satisfy the legal obligation of building owners.

2.3 Building Regulations and Warrants of Fitness

The second schedule to the Building Regulations requires specific building systems and features (eg sprinklers and escape routes) to be subject to regular inspection and

maintenance. The frequency of these actions is dependent upon the relevant system or feature. At least once each year an Independent Qualified Person (IQP) is also required to inspect and/or check the relevant systems and features to certify their suitability (or otherwise) to the building owner. The owner is then required to complete a Warrant of Fitness for the entire building.

The clear objective of this provision is to ensure that items effecting the safety of occupants will be in good operational condition whenever required. The inspection and maintenance regime for the relevant system or feature is generally prescribed to be necessary and sufficient to ensure a good operational condition. Over-testing may result in failure at a critical time as much as non-testing may.

2.4 Fire Service Act

The Fire Service Act 1975 (NZG 1998) is largely an Act to establish the New Zealand Fire Service (NZFS) and to consolidate and amend the law relating to protection of life and property from fire and certain other emergencies. The principal context of the Act therefore relates to the establishment, organisation and provisions for the operation of the NZFS. The Fire Safety and Evacuation of Buildings Regulations (NZG 1995) have been issued under the authority of S92((3)(a) of the Act where -

"...owners or occupiers of buildings used for such purposes may be prescribed in the regulations -

- (a) To provide schemes to the satisfaction of the Commission for the expeditious and efficient evacuation of persons from the buildings and the prevention of panic among them in the event of the buildings being endangered by fire; and*
- (b) To make such reasonable provision as may be necessary (having regard to all the circumstances of the case) for the testing of the schemes"*

2.5 Fire Safety and Evacuation of Buildings Regulations

2.5.1 Evacuation Procedure

Section 4 of the Fire Safety and Evacuation of Buildings Regulations commences-

"The owner of every building shall provide a procedure for the safe, expeditious and efficient evacuation of the occupants of the building from the scene of a fire.."

Evacuation schemes are required to be approved by the National Commander of the NZFS, and trial evacuations are required generally at a maximum of 6 monthly intervals.

2.5.1 Escape - Evacuation Schemes

The Building Industry Authority has prepared rules called the Acceptable Solutions for the design for safe escape from buildings as a means of compliance with the Building Code. The general concept at the time of introduction of the Building Code was that if a building complied with its provisions then it would be sufficient to ensure the safety of the building occupants, except as may be specifically required in any other act. This is specifically noted in S.7(2) of the Act.

This would appear to imply that the evacuation scheme would solely rely upon ensuring a suitable management regime for the safety of the building occupants. Building fire safety measures required in excess of the Building Code (and the Acceptable Solutions) can not be required except as specifically provided in any Act. The Fire Safety and Evacuation of

Buildings Regulations, does not contain any such requirements. There is no publicly published equivalent of the BIA's Acceptable Solutions to the Building Code for the Fire Safety and Evacuation of Buildings Regulations. But it is clear that the NZFS are requiring (through in-house procedures) fire safety measures in excess of the Acceptable Solutions for Sleeping Care type occupancies (ie hospitals and rest-homes) before granting approval to an Evacuation Scheme. It appears likely however that the establishment of safe Means of Escape by logical design processes, which will comply with the relevant legislation, should permit ready approval of an evacuation scheme.

The loss of lives in some small rest-home fires (SC occupancy) attracted significant media attention and public reaction requiring that increased protection should be provided to occupants in such occupancies. While the safety of occupants is the principal objective of the Building Code safety at any cost is inappropriate. Until rational risk and cost-benefit analyses are developed such reflex reactions by the public the response by organisations such as the NZFS can be expected by way of excessive levels of safety provisions.

Where there is no approved Evacuation Scheme the owner of the building commits an offence and may be fined for every day or part day that the offence is committed. As far as the writer is aware the authority by which the NZFS requires provisions in excess of the Acceptable Solutions has not yet been tested with the Building Industry Authority, or any test case taken to the courts.

2.6 Summary

- * The Building Code objective with respect to Means of Escape is -
 - "(a) Safeguard people from injury or illness from a fire while escaping to a safe place, and
 - (b) facilitate fire rescue operations."
- * Means of Escape are required to comply with the Code in all new buildings and as nearly as is reasonably practicable in existing buildings subject to alterations or changes of use.
- * Acceptable Solutions are set out in the Building Industry Authority Handbook to the Building Code. These solutions are at times conservative and/or difficult to apply as they are prescriptive. There is some doubt as to whether their application will always comply with the stated Building Code objective.
- * Any variation from the Acceptable Solutions requires the designer to consider all the relevant factors for the design of safe Means of Escape.
- * The Fire Safety and Evacuation of Buildings Regulations require regular drills to confirm the effectiveness of the escape routes, and may require safety features in excess of those of the Acceptable Solutions.

Chapter 3. Fire Incidents

3.1 Fires in New Zealand

Reference to NZFS (1997) statistics (Tables 3.1 to 3.12) provides a picture of the extent of fires, causes, fatalities, injuries and dangers in a local context. Unfortunately the reports from Wood (1972), Bryan (1977) and Bryan & Milke (1981) do not provide directly comparable data because of the different data groupings.

The NZFS data reports on structure fires and other property fires (which includes home appliances etc, but with no structural damage). Looking first at the property involved in fires (including structures and other property), Table 3.1 shows a summary over the last 5 years for which data is available at an average of over 17,000 fires per year as below.

Table 3.1 Summary of Property Involved In Fires

	1993		1994		1995		1996		1997	
	no.	%	no.	%	no.	%	no.	%	no.	%
Public Ass'y	675	4.2	859	4.8	956	5.1	957	6.3	902	5.3
Education	403	2.5	428	2.4	441	2.4	347	2.4	457	2.7
Health & Detention	236	1.5	220	1.2	215	1.1	192	1.3	253	1.5
Residential	6990	43.4	7452	41.5	6598	35.2	6268	41.5	6670	39.0
Shop & Office	741	4.5	656	3.6	705	3.8	721	4.8	899	5.3
Primary Ind'y & Utility	935	5.8	1404	7.8	1432	7.6	1126	7.5	1174	6.9
Manufacturing	525	3.3	572	3.2	559	2.4	453	3.0	569	3.3
Storage	763	4.7	746	4.1	752	4.0	455	3.0	576	3.9
Special	<u>4855</u>	30.1	<u>5639</u>	31.4	<u>7065</u>	37.3	<u>4589</u>	30.4	<u>5594</u>	32.7
Total	<u>16123</u>		<u>17976</u>		<u>18723</u>		<u>15108</u>		<u>17094</u>	

Table 3.1 indicates that the number of fires has been relatively constant in total and across the various building groups.

The Government Statistician (1995) indicates that there are approximately 1.2 million occupied permanent private dwellings in NZ. It appears reasonable to assume that there are probably around 2 million buildings in the country which gives an average annual probability of approximately 0.01 for a property fire. This rate appears low, a probability figure of 0.02 (1 in 50 years) has been mentioned in discussions (unrecorded), and appears more likely. The probability of building fires will be significant in considering the risk of occurrence.

Also significant are the causes of fires and where they originate. The NZFS statistics provide this information for structure fires, these are shown in Table 3.2.

Table 3.2 Structure Fires - How they Started

	1993		1994		1995		1996		1997	
	no.	%	no.	%	no.	%	no.	%	no.	%
Deliberately . Lit Fires	819	20.0	830	21.1	762	21.1	88	20.7	677	24.1
Reckless Fires	24	0.6	80	2.0	98	2.7	82	2.9	91	3.2
Careless with Heat Source	936	22.6	1052	26.7	919	25.5	705	24.8	638	22.7
Careless with Mat'ls Ignited	413	10.1	263	6.7	242	6.7	107	3.8	84	3.0
Mechanical Failure	773	18.9	630	16.0	611	16.9	509	17.9	503	17.9
Design or Installation Deficiency	242	5.9	264	6.7	233	6.5	159	5.6	137	4.9
Operational Deficiency	489	11.9	464	11.8	407	7.3	263	9.3	240	8.5
Extreme Conditions	33	0.8	41	1.0	46	1.3	7	0.2	17	0.6
Other Causes	<u>368</u>	9.0	<u>309</u>	7.9	<u>290</u>	8.0	<u>421</u>	14.8	<u>426</u>	15.1
Total Structure Fires	<u>4097</u>		<u>3933</u>		<u>3608</u>		<u>2841</u>		<u>2813</u>	

Table 3.2 indicates that while the number of structure fires has decreased overall over the last five years with hover an increasing proportion of fires being deliberately lit or as a result of some other than the unspecified cause.

While these (structure fires) may cause the most property damage it must be remembered that smoke is the major cause of fatalities, not the fire to the building.

Structure fires in other than residential properties initiated largely in storage areas, roof/ceilings and assembly/sales areas. A small, but unacceptable, number (3%) commenced in Means of Egress. Wood (1972) indicates that the majority of dwelling fires occurred in kitchens followed by living rooms and bedrooms. Standards Australia (1996) lists the sequence as kitchens, followed by bedrooms. Table 3.3 shows the locations where structure fires were started. It appears likely that property fires in general would provide a similar distribution of locations. There is a significant decrease in the fires, over the period tabled, in Assembly or Sales Areas. Unfortunately there is no explanation or discussion in the statistics relating to these figures.

The NZFS (1997) statistics indicate that approximately 14% of structure fires were initiated by cooking equipment and appliances. Over 20% of structure fires were deliberately lit, with 30% a result of carelessness with a heat source or ignited materials. Mechanical failure or deficiency in design, installation or operation of equipment initiated approximately 35% of property structure fires. This data is summarised in Table 3.4.

Table 3.3 Structure Fires - Room or Space Where Fire Started

	1993		1994		1995		1996		1997	
	no.	%	no.	%	no.	%	no.	%	no.	%
Means of Egress	142	3.5	73	1.9	52	1.4	126	4.4	114	4.1
Assembly or Sales area	512	12.5	531	13.5	521	14.4	69	2.4	71	2.5
Living Areas	1422	34.7	1344	34.2	1223	33.9	1289	45.4	1218	43.3
Technical Areas	183	4.5	117	3.0	94	2.5	65	2.3	65	2.3
Storage Areas	716	17.5	665	16.9	667	18.5	551	19.4	560	19.9
Service Facilities	139	3.4	129	3.3	112	3.1	31	1.1	31	1.1
Service or Equipment Areas	246	6.0	244	6.2	172	4.8	115	4.0	120	4.3
Structural Roof/Ceiling Areas	570	13.9	624	15.9	606	16.8	335	12.6	358	12.7
transportation/vehicle Areas	31	0.8	26	0.7	12	0.3	18	0.6	20	0.6
Outside and Multiple Areas	136	3.3	180	4.6	149	4.1	161	5.7	203	7.2
Other Area of Origin	<u>0</u>	0.0	<u>0</u>	0.0	<u>0</u>	0.0	<u>81</u>	0.0	<u>47</u>	2.9
Total Fires.	<u>4097</u>		<u>3933</u>		<u>3608</u>		<u>2841</u>		<u>2813</u>	

Table 3.4 Structure Fires - Equipment Involved in Ignition

	1993		1994		1995		1996		1997	
	no.		no.		no.		no.		no.	
Heating Systems	385		397		344		118		113	
Cooking Eq't	326		326		293		124		105	
Air Cond. or Refrig. Equip't	34		28		29		19		17	
Elect'l Dist'n Equipment	359		375		385		115		110	
Appliances & Elect'l Equip't	276		256		206		114		111	
Specialist Equipment	42		20		17		19		17	
Processing Equipment	56		71		36		67		58	
Service or Maintenance	88		105		99		26		34	
Other Equip't	53		44		42		13		12	
No Equipment involved in ignition	<u>2478</u>	60.6%	<u>2311</u>	58.7%	<u>2157</u>	60.1%	<u>2226</u>	78.4%	<u>2236</u>	79.5%
Total Fires	<u>4097</u>		<u>3933</u>		<u>3608</u>		<u>2841</u>		<u>2813</u>	

Consideration of the likely causes and locations of fires is important, and may usefully reflect the information above, in the design for Means of Escape. Because of the significance of the egress route all practicable steps must be taken to minimise the potential for ignition within these areas. Site management is beyond the control of the design engineer. However, ensuring that the presence of switchboards and other equipment is minimised, and giving attention to surface finishes (particularly with a single means of egress) will reduce both the probability and the effect of any fire on those escaping from a building.

3.2 Fire Fatalities

Table 3.5 Deaths At Fires

	1993	1994	1995	1996	1997
Building Occupancy in fire related deaths					
Residential	26	24	31	23	36
Vehicles	3	13	13	8	14
Other	0	2	2	0	1

The number of fatalities are cited as all being in fires, but as previously noted smoke, in an enclosed space could be fatal. Table 3.6 indicates the actions of those killed in all fires (not only building occupancies). It can be seen that a small number resulted from attempting to control the fire, whether any of these were firemen is not included in the data. The most significant category is 'sleeping' generally followed by Unable to Act, or Escaping. The statistics do not, unfortunately separate out the actions in structure fires from those through motor vehicle or other incidents.

Table 3.6 Victims action immediately before the fatality

Action	1993	1994	1995	1996	1997
Escaping	3	5	11	6	7
Rescue attempt	1	2	2	0	1
Fire Control	2	2	2	0	1
Response or return	0	1	0	0	0
Sleeping	11	11	12	9	9
Unable to Act	4	7	4	4	5
Irrational Action	6	0	5	1	2
Other Action	4	11	10	12	26

The design for Means of Escape frequently must consider the age of the occupants. The significance of this is indicated by Table 3.7. It is clear the age group decade most at risk is 0-9 years. Given the generally smaller population size in the decades from 70 onwards it appears likely that with increasing age there is an increase in risk in these groups as well. The very young and the elderly are also those most likely to be asleep or unable to move, providing a strong linkage to the actions immediately before death.

Table 3.7 Age of those Killed

Age	1993	1994	1995	1996	1997
0 - 9	6	3	10	9	10
10 - 19	6	3	4	3	5
20 - 29	6	9	5	3	7
30 - 39	2	3	3	5	11
40 - 49	0	8	4	4	4
50 - 59	4	1	4	3	2
60 - 69	1	2	5	3	4
70 - 79	2	1	3	1	2
80 - 89	4	1	1	0	4
over 89	0	8	7	1	2
Total Fire Fatalities	31	39	46	32	51
Number of Fires where Fatalities Occurred	22	30	31	28	36

Considering further therefore, the most significant actions immediately prior to fatality were-

* sleeping/unable to act	38%
* escaping	21%.

Those most at risk (0-9 and 70+ age groups) constituted 38% of fatalities.

There is close correlation between the fatalities and the most susceptible groups, as expected. However some care is required in using these figures because, as noted previously, only 70% of fatalities occurred in structure fires.

The data does not indicate the number of fatalities in residential or other structure fire situations. The necessity/scope for improvement is therefore uncertain.

3.3 Systems Operations

Fire sprinkler performance is shown in Table 3.8. The data indicates that despite the greatest incidence of fires being in residential property, the very low incidence of sprinkler installation is reflected in the very small number of cases where their operation was initiated.

Table 3.8 Fire Sprinkler Performance in Structure Fires

	1993	1994	1995	1996	1997
Public Assembly	3	4	3	1	1
Education	1	2	0	0	0
Health Care and Detention	10	20	14	5	6
Residential	7	3	7	2	2
Commercial	10	8	8	3	2
Basic Industry and Utilities	2	1	2	0	0
Manufacturing	20	27	28	7	8
Storage	3	1	3	3	1
Special	2	1	4	0	0
Total	67	67	69	21	34

A number of fires resulted in calls to the Fire Service, but were too small to activate the sprinkler system as reported in Table 3.9. Unfortunately due to industrial action of the NZFS staff, full records appear not to have been kept for the 1996-97 period.

Table 3.9 Fire Too Small to Cause Operation of Sprinklers

	1993	1994	1995	1996	1997
Public Assembly	5	14	5	0	0
Education	2	3	1	0	0
Health Care and Detention	27	19	13	1	0
Residential	4	5	3	0	0
Commercial	9	20	11	0	0
Basic Industry and Utilities	2	0	3	0	0
Manufacturing	31	27	23	1	0
Storage	2	2	2	1	0
Special	0	1	0	0	0
Total	82	91	61	3	0

Table 3.10 Automatic Detector Performance in Structure Fires

	Detector in space of fire origin operated					Detector not in space of fire origin operated				
	1993	1994	1995	1996	1997	1993	1994	1995	1996	1997
Public Assembly	6	4	7	1	1	1	3	0	1	1
Educating	5	10	10	4	4	1	2	2	0	0
Health Care & Det'n	12	7	8	6	11	0	3	1	1	1
Residential	21	12	10	18	14	6	2	5	11	10
Commercial	12	11	13	10	5	2	2	0	0	1
Basic Ind & Utilities	7	3	3	0	2	0	0	1	0	0
Manufacturing	25	16	9	12	5	3	2	0	1	0
Storage	3	1	1	3	3	0	0	0	0	0
Special	2	1	2	1	1	0	1	0	0	0
Total	93	65	63	55	54	13	15	9	14	13

Heat and smoke detectors are required, and installed, in many premises. An average of nearly 80 instances of detector operation was recorded over each of the last 5 years (Table 3.10). Table 3.11 shows that an average of nearly 20 instances each year is recorded where detectors failed to operate despite the size of the fire, and a similar number were recorded where intervention action was taken before the fire was sufficient to activate the detector. The failure to operate in 20% of fires is a concern. Attention to maintenance is essential to maximise the effectiveness of such systems, particularly where occupants rely upon them for their safety. However, the benefits in the 80% successful operation must not be ignored. There may be more fires where detectors operated and occupants put out the fire with calling the NZFS.

Table 3.11 Automatic Detector Non-Performance in Structure Fires

	Detector in fire origin space should have operated					Detector in space of fire origin/fire too small				
	1993	1994	1995	1996	1997	1993	1994	1995	1996	1997
Public Assembly	2	4	3	0	1	1	2	5	1	1
Educating	3	3	6	1	0	1	3	0	0	0
Health Care & Det'n	6	4	5	0	5	11	13	4	4	0
Residential	2	5	5	0	3	3	0	1	1	1
Commercial	4	4	3	2	0	11	6	7	0	0
Basic Ind & Utilities	1	1	0	0	2	0	1	0	0	0
Manufacturing	7	1	4	1	2	1	3	2	1	0
Storage	2	0	1	2	0	1	0	0	0	0
Special	0	0	0	0	0	1	0	1	0	0
Total	<u>27</u>	<u>22</u>	<u>27</u>	<u>9</u>	<u>12</u>	<u>30</u>	<u>28</u>	<u>20</u>	<u>7</u>	<u>2</u>

Domestic smoke alarms (Table 3.12) are installed in only a very small proportion of New Zealand dwellings - but in increasing numbers as a result of the media and Fire Service publicity. It is a concern however that for a variety of causes, including the need to replace batteries or the disarming to prevent vexatious alarms, resulted in approximately 15% of instances where these domestic alarms did not operate. Given that the majority of fatalities arise from asphyxiation from fires in dwellings the failure of these alarms is a concern. However the installation and correct management of these devices is seen by the writer as being a potentially vital factor in decreasing dwelling fatalities.

Table 3.12 Domestic Smoke Alarm Performance

	1993		1994		1995		1996		1997		Avg
	no.	%	no.	%	no.	%	no.	%	no.	%	
Domestic smoke alarm in space operated	46	74.2	40	85.1	44	76.6	43	97.7	44	97.8	85.4
Domestic smoke alarm in space did not operate	<u>16</u>	25.8	<u>7</u>	14.9	<u>12</u>	21.4	<u>1</u>	2.3	<u>1</u>	2.2	14.6
Total	<u>62</u>		<u>47</u>		<u>56</u>		<u>44</u>		<u>45</u>		

3.4 Summary

- * Approximately - 40% of all property fires occur in residential properties
30% in other buildings, and
30% in special property (tunnels, garbage sites, road-sides, railways, outdoors etc)
- * The main causes of structure fires were-
cooking equipment and appliances 14%

arson	20%
carelessness with fire etc	30%
mechanical failure or deficiency	35%

- * The most significant actions immediately before fatality were-

sleeping/unable to act	38%
escaping	21%
- * The age groups most at risk; 0 to 9yrs and 70yrs+ totaled 38% of fatalities.
- * Improvements to warning systems and Means of Escape in buildings may be able to reduce the risk and incidence of fatalities to these groups.

Chapter 4. Establishment of Occupancy Numbers

4.1 Introduction

Other than for very low occupancy numbers some of the most significant factors affecting the Means of Escape are -

- * the actual number of people present in a building at the time of a fire;
- * their location within the building with respect to the fire; and
- * the numbers having to use any particular escape route.

4.2 Purpose Group Activities - Known and Potential

Some Purpose Groups control the occupancy by the number of fixed seats or the number of bed spaces (but watch for bunks). For other purpose groups the occupancy is based on the floor area. The Acceptable Solutions provides (in its Appendix A Table A2) density ratios in terms of persons/m² of floor area for a range of purpose group activities. This Table is duplicated in Appendix D of this report. The source of this table, also used by Buchanan (1994) is not known. Buchanan also notes that the numbers may be calculated on the basis of the net area being occupied.

The problem with using the net area lies in the lack of definition of what actually is or is not included in the area. Few items are fully fixed in any premises. However any specific purpose group activity will generally involve a ratio of net to gross area that is relatively consistent within the purpose group (for economic viability).

In this respect it is also more simple to define the gross area which is known (or proposed) at the design phase, rather than the net area which may depend upon the owner's specific fit-out.

Gross or net areas may be used to determine the numbers of occupants provided the basis is clearly stated in the design for Means of Escape.

It is necessary to review the proposed scheme plan and determine the activity in each room or space. For instance a small retail shop may have areas used for -

- * customer purchase selection;
- * counter staff;
- * management, office;
- * storage and inwards goods;
- * staff room;
- * toilets;
- * corridors and aisles; and
- * entry/exit.

For the proposed purpose use it will be necessary to establish the size (in plan area) and location of fittings and fixtures. For our shop example this will include -

- * display stand;
- * counters;
- * freezers/chillers etc;
- * shelving;
- * desks, filing cabinets; and
- * tables, sinks.

The balance of the areas are available for "occupancy".

The numbers of occupants in each area needs to be calculated, allowing for the following:

- * corridors and passageways only being used for circulation have a nil occupancy load; and
- * Toilets and rest-rooms being used by persons included into occupancies in other areas also have a nil occupancy;

Staff rooms are normally used by persons included into occupancies in other areas. However it may still be necessary to consider the situations where -

- * the staff room is empty and staff are at their normal location; and
- * the staff room is full and staff numbers at other areas are reduced proportionally.

Where only a general description of the purpose group is available the designer will need to:-

- * ensure the owner/developer is aware of the generality of such design assumptions; and
- * design with due conservatism for the range of potential users within the description provided.

At the other extreme a building may be "purpose-built" for a particular client, with specific fixtures and defined staff numbers. Establishment of activities, occupancy numbers and locations may be straight forward. Conservatism in the design for Means of Escape (and in general) may still be appropriate to provide flexibility for future changes.

The owner/developer should be made aware of the limitations of the initial design on future developments.

4.3 Occupancy Numbers

As noted above the Acceptable Solutions provides a table of occupancy densities in terms of persons/m² for a wide range of purpose group activities.

However the writer notes that some care is required in this respect as higher densities may be warranted, as shown in this chapter. Direct comparison between the occupancy activities tabled may not be practicable. Conservatism in assessment of occupancy numbers (using a higher density ratio, requiring an increase in the loading and time required for escape) may be appropriate.

4.3.1 Classrooms

If allowance is made for circulation areas in front of blackboards, noticeboards, screen etc and for general access then the occupancy numbers for classrooms using the balance of the area and the density value in the Acceptable Solutions appears appropriate (ie the space occupied by desks and chairs are not considered).

4.3.2 Gymnasia

The numbers that may be present in a school gymnasium appears excessive for sports or gymnastic exercises to be carried out. If considered for bench seating or for assembly purposes the occupancy numbers could be achieved.

4.3.3 Public Bars

On a very limited survey the calculated numbers of occupants at peak times in popular bars appears to be less than may actually occur.

4.3.4 Cinemas

The determination of occupancies in cinemas requires care, particularly with multiplex operations. The maximum number of occupants in each cinema may be taken as the actual number of seats available; but there may be considerable numbers of patrons waiting in the foyer for the next showing. It appears to be practice for only a short break (10-15 minutes) between screenings and there can easily be over 50% of the patrons waiting for the next screening - as more than one cinema may change within a few minutes (resulting in waiting for more than one cinema). A fire which requires egress through the foyer could readily result in crowding of the escape route, which generally includes stairs.

4.3.5 Grocery Supermarkets

It was intended to undertake a survey of a supermarket during the peak pre-Christmas periods (December 1998) however management of the chain denied permission for an official study. The writer however, in personally frequenting the supermarket, noted numbers in the shop (by departments/areas/aisles). The supermarket operated significantly extended hours prior to Christmas, and it appears that the peak crowds of previous years did not eventuate. Visits to other supermarkets also failed to encounter extra heavy occupancy densities noted from previous experience. Observations taken of a supermarket are noted in Appendix A.

It was noted in grocery and similar supermarkets significant space was occupied by shopping trundlers. These are approximately 1m^2 each. In a fire situation it is not known whether -

- * the trundlers are left behind the checkout counters - which will hinder access or escape through that area; or
- * patrons are permitted to exit with their trundler. As only one trundler can be manoeuvred through even a double door, congestion will occur and the rate of escape slowed.

From the observations made the maximum occupancy encounters in the supermarket was in the queuing area to the checkout counters. The maximum occupancy density in this area was approx 0.9 persons per square metre (p/m^2). It is considered likely that the maximum likely density in this area could be $1.2\text{p}/\text{m}^2$.

It is considered unlikely for the whole store to be crowded to the extent of the maximum estimated above due to:-

- * limited availability of parking; and
- * limited availability of trundlers; and
- * peak periods involve queuing for over 15min at the check-out

On a whole store basis it appears likely that the maximum shop floor density may exceed the $0.5\text{p}/\text{m}^2$ of the Acceptable Solutions for short periods.

4.3.6 General Retail

Retail stores where shopping trundlers are not used may, particularly at times of sales, be expected to achieve densities in excess of the value noted in the Acceptable Solutions of $0.4\text{p}/\text{m}^2$.

4.3.7 Office Buildings

The Acceptable Solutions provides for general offices to have densities of $0.1\text{p}/\text{m}^2$. Purser (1995) notes that studies of Canadian office buildings suggest an average of closer to $0.04\text{p}/\text{m}^2$ of rentable area. Being a gross area, allowance may be necessary for office fixtures, fittings and circulation areas etc. Tutt and Adler (1981) indicate that for offices the

workplace area should allow further an approximately 20% for circulation and 20% for filing, fixtures etc; this increases the density on net area to over 0.06p/m^2 . The assessment therefore of net area may have a significant effect on the numbers of occupants using the Means of Escape during an evacuation.

A survey of 5 multistorey office buildings in Wellington has been undertaken. The tenants of various occupancies were requested to provide information with respect to their rentable floor area, the number of occupants and some additional information about their business activities and the ancillary areas rented (eg toilets etc). The information provided very little information other than the gross rentable areas and the number of occupants. The survey form is included with tabulated results in Appendix B. Occupancy densities ranged between 0.019 and 0.091p/m^2 of gross area, with a median of 0.057 p/m^2 , standard deviation of 0.024p/m^2 and standard error of the mean of 0.005p/m^2 .

The survey attempted to separate out individual activity areas within office tenancies, but there was insufficient response to the specific questions to establish any useful design information. Also, there was insufficient information to differentiate the few offices where toilets and lift lobbies were incorporated into the total areas.

It was noted that approx 10% of the rentable area in each of the survey buildings was untenanted at the time of survey. Such vacancies would further reduce the overall density. The Canadian occupancy densities appear low by comparison with the current survey. If 20% of gross area is taken for each of circulation and fixtures and fittings the average survey figure of 0.057p/m^2 of gross becomes very close to the 0.1p/m^2 of net area of the Acceptable Solutions. It appears desirable to consider higher densities for design in NZ conditions.

The responses do indicate a trend towards higher densities with increased number of occupants. The most frequent density occurred in the band 0.02 to 0.0295 p/m^2 .

It is recommended for specific design that unless specific numbers are known or the net area is confirmed (and the relevant density is used) then the designer should consider whichever produces the more critical condition of the following:-

- * a value of 0.08 p/m^2 of the gross area on the fire floor and 0.06p/m^2 of gross area on the other floors, when considering egress and merging of evacuating occupants; or
- * a value of 0.08p/m^2 of the gross area on the top floor and 0.06p/m^2 of gross area on the lower floors.

4.4 Circulation and Escape Routes

Circulation and escape routes are to be kept free for movement by occupants. The Acceptable Solutions provides limitations on width and length of escape routes, but not generally for circulation routes. The width (within limits) relate to the maximum numbers of occupants from any one floor who may use the escape route. Other than in the Dead End Open Path this is based also upon any one of the escape routes being unavailable because of the effects of fire.

The Acceptable Solutions also specifies limits on the slopes of ramps and dimensions for stairs depending upon their likely general use.

Routes designated for escape purposes will require to be identified on the plans and consideration should also be given to the location of signs and emergency lighting.

Specific design may be used for escape routes that are outside the width, length and slope limits of the Acceptable Solutions (see Chapter 10). Where unavailability of any one route is

to be considered the critical time for escape along the designated routes will need to be determined.

4.5 Time of Day

The numbers of occupants in a building may depend significantly upon the time of day. The available Means of Escape may also vary with this factor (eg security reasons may result in some doorways being locked outside normal working hours). In some situations the maximum occupancy may vary over a relatively short period of time (see Section 4.3.4), in others may be relatively constant (eg rest-homes), and in others be high during the day and minimal during the night (eg commercial offices). The escape conditions will need to be assessed with respect to the relevant occupancy and the appropriate fire scenario.

4.6 Change of Occupier

Where a change of occupier occurs in conjunction with a change of use, a new fire safety design is required. Design for compliance with the Building Code is required, and has to be submitted to the Territorial Authority (TA) for Building Consent approval.

Where a change of occupier, but no change of use, occurs in conjunction with alterations for which a building consent is required, then the Means of Escape must also be considered. Design for compliance with the Building Code must be incorporated into the Consent application.

Where a change of occupier but no change of use occurs, the potential exists (particularly for buildings which have been subject to specific fire design), for the invalidation of the original design assumptions. While the implications of specific fire design may be lost with the change of occupier, the responsibility for ensuring the safety of occupants lies with the owner of the building. In the writer's opinion awareness of many building owners and occupiers of the implications of fire safety design is minimal.

The Acceptable Solution values approximate to typical occupancy densities. The design must therefore consider either:-

- * the potential for higher (worst case scenario) densities must be provided for with suitable margins for safety; or
- * the specific maximum likely (worst expected case) with a reduced margin for safety.

This may be considered equivalent to the structural engineer's 'ultimate limit state' for the loading density with the application of an 'undercapacity factor' as being applied to the Means of Escape.

4.7 Summary

- * Establishment of occupancy numbers requires, as a first step, determination of the areas allocated to specific purpose group activities.
 - * Occupancy numbers may be determined from the Acceptable Solutions or from specific design allocation.
 - * A survey has been taken to determine typical NZ values for occupancy densities.
 - * Net or gross density values may be used provided it is clear which of these is being applied in the determination of the number of occupants requiring to escape. *
- Changes of use and alterations require design for Means of Escape from fire.

- * Changes of occupier, even with no change of use or alterations, may result in (unwitting) invalidation of specific fire design for Means of Escape.
- * The margin of safety should be commensurate with the degree of certainty of the occupant densities.

Chapter 5. Fire Detection Systems

5.1 Introduction

While the majority of fires are detected by those close to a fire recognising the smoke (smell or sight), or flame (noise, heat or light) the safety of occupants may depend upon an automatic detection system. The detector system may initiate -

- * automatic fire suppression action
- * automatic smoke control activation
- * occupant evacuation
- * manual fire suppression
- * fire service response

Each detector system has characteristics which determine its effectiveness in these actions; the relevant characteristics need to be recognised in the design for escape of occupants.

The size of the fire, the rate of growth, the type of combustibles, the fire compartment characteristics and the type and location of the detector system may all need to be considered in determining the activation time of any particular system.

5.2 Manual detection

Where occupants are close to the fire, and awake, the first cues from the fire (smell, visible smoke or flame) may be detected at a very early point in the combustion process. Because of the insidious nature of smoke from the smouldering phase persons who are asleep may not be aroused, even in the same room, unless it results in a more unaccustomed event, such as the sound of breaking glass.

Where occupants are further away, possibly in another room, the fire may grow to a considerable size before cues are received and recognised by the occupants. In these instances the cue may be the sound of the fire, breaking glass, smell, visible smoke or flame. Once the cue is recognised it is normal for occupants not in the immediate vicinity of the fire to investigate to confirm the cue before activating any alarm that is present, warning others in the vicinity and commencing to escape (Wood, 1972; Bryan & Milke, 1981; Bryan, 1983; Canter, 1990a)

5.3 Smoke Detectors

Smoke detectors may be of the point-type (ionisation or optical), beam type or aspirating.

Point-type detectors are mounted at discrete points throughout a firecell and rely upon smoke entering a chamber where it is detected either by ionisation of the smoke particles or light scattering by the smoke particles inside the compartment. Mulholland (1995) indicates ionisation detectors tend to being more sensitive to high concentrations of smaller (<0.3 microns) particles such as produced by burning of paper and wood, but less sensitive to the larger smoke particles more common in smouldering fires. Ionisation detectors are also very sensitive to products resulting from cooking fat fires, and are not therefore recommended in or close to kitchens. The optical scatter type have the opposite characteristics.

There are some detectors which incorporate both actions. The sensitivity of each type of detector may be adjusted, within limits, and the appropriate adjustment needs to be made to minimise vexatious activation because of excessive dust, cigarette smoke, etc.

Beam detectors operate by directing a light beam from a source point to a receiver and activates the alarm at detection of changes in the light received. As with the point-type optical detector the effectiveness is a function of the smoke characteristics, including the particle size. These detectors are generally more appropriate to longer and higher volumes than the point type detector. It is also possible to mount the source and receiver at near ground level, and use reflectors mounted near the roof level. This assists in general maintenance, at some loss of range, but still requires access to the reflectors at regular intervals.

Aspirating detectors draw air from points into a pipework system for sampling at a central point by a sensitive light scattering detector. The sensitivity of this type of system may be set to detect smoke particles at as low as 10% of the standard point-type detector, and are therefore probably more appropriate for areas with generally 'clean' air and where the earliest detection is required (excepting possibly flame type detectors).

All these detectors require the combustion products to be carried by the plume or ceiling jet into or past (in the case of beam type) the detector. The response of the detector, once the particles arrive at the detector, are almost instantaneous. There is a small delay for the aspirating type to draw the sample into the testing chamber.

5.4 Heat Detectors

Heat detectors, which include sprinkler heads, respond to heat transfer from the ceiling jet. The response is a function of the temperature and velocity of the jet at the detector location and the detector characteristics. The location both with respect to distance from the fire and below the ceiling soffit are both significant factors in the effectiveness of these detectors. Detector heads are set to be activated at specific temperatures (suitably above expected ambient), but because of the thermal mass of the individual heads there is a time lag in the actual response while the detector head is brought up to the activation temperature by the ceiling jet.

Some vane type heat detectors are activated by a specific rate-of-temperature rise; and may not then be activated by a slow growing fire. Sprinkler heads which generally have a larger thermal mass than the vane type detector may not be activated as quickly as these latter systems. Sprinkler systems are expected to provide alarm activation instantaneously with activation, and to commence suppression (with a short delay where a dry pipe system is installed).

5.5 Flame Detectors

These detectors are activated by radiated light emissions, often being set for particular wave bands such as infra-red through to ultra-violet as may be relevant to certain flame temperature and emissivity. These detectors may be set for directional response; with the possibility for off-axis response to be carefully considered, as there will be a distinct variation in sensitivity in these conditions.

5.6 Gas Detectors

Advances in technology now also permits the installation of detectors for various gases. It appears practicable, for example, to effectively measure variations in CO even above a ceiling which may prevent penetration by smoke particles in sufficient quantity to activate a smoke detector. Such installation will require careful acceptance testing to ensure that the system provides the necessary warning and time for evacuation.

5.7 Alarm/Warning Connections

Detector systems are generally set to activate a warning alarm for building occupants. Single point type smoke detectors are battery powered and are suitable to be installed in domestic situations. Unfortunately these devices are frequently disarmed by occupants because of problems with vexatious activations through smoke from cigarettes or burnt toast etc, or through insufficient charge in the battery. Nonetheless their record of providing warning has been proven advantageous. Probably more education is required on the appropriate location and when to install a new battery (say at each change of day-light saving). A more expensive option for dwellings and other small premises is available as a hard-wired system for heat and smoke detectors. Advances in technology are bringing prices down to more acceptable levels for the more expensive domestic dwellings.

In considering more extensive installations and with the increase in sophistication of electronic systems it is possible to design alarm systems that-

- * indicate the specific location of the activated detector;
- * do not provide a general warning as soon as the alarm is activated; and
- * activate suppression devices other than sprinklers.

These systems generally require installation of local alarm panels and often computerised logic to ensure that the system is not manually overwhelmed or ignored. Such systems are common in facilities such as hospitals where a general evacuation may be unacceptable, particularly for a minor event.

Alternative suppression systems, involving CO₂ or Energen (a proprietary gas system) etc may be appropriate for cabinet type electrical installations, and may be activated by a detector within the cabinet itself.

It appears, to the writer, that automatic systems should also always have a manual call system. In many instances the fire may be discovered before the detector system will activate. It is important, for escape, that the earliest possible warning be given to occupants. This approach is also taken by the Acceptable Solutions.

The Acceptable Solutions, as discussed earlier, allows for increases in the basic escape path travel distances depending upon the type of detector system installed. For further life safety, some occupancies require the installation of both sprinklers and smoke detectors.

5.8 Modeling Responses

The designer of the Means of Escape needs to consider the time at which occupants receive warning of the fire. Where the cue received is from an automatic detector it will be necessary to consider -

- * the type of detector system, and its response characteristics to fire;
- * the source of the fire; and
- * the size and rate of growth of the fire.

Consideration should be given to the possibility that the fire may not be of the nature for which the installed detector is most effective.

Smoke detectors may be activated by a smouldering fire. Not all computer simulation programs have a routine for this action. FIRECALC appears to consider this possibility. For smoke detection from burning conditions most programs (eg FPETOOL, DETACT-QS) consider detection as a heat detector at 13°C above ambient. For slow fires or high ceilings these programs indicate long times before detector activation.

Heat detectors (thermal and sprinkler) are generally set to operate at specific temperatures with their response also dependent upon their thermal characteristics (measured as Response Time Index or RTI in terms of $(\text{ms})^{0.5}$). Common temperature ratings are- 58°C - 88°C and 88°C -132 °C. At least not less than the mid-range temperature is recommended for modeling of this factor.

The RTI for fixed temperature vane type detectors may be taken (Standards Australia, 1996) as

	10 - 20 $(\text{ms})^{0.5}$,
whereas for sprinklers RTI's may be-	
* fast response	30 -100;
* soldered link	150;
* 8mm glass bulb	200 - 300 $(\text{ms})^{0.5}$,

As with the temperature ratings it is recommended in modeling/calculations not to use the lower values. The upper end of the selected range for the specified model should be used because of the variations in the responses of the individual detector heads. The relevant design data must be incorporated into the construction documentation.

5.9 Detector Reliability

Statistics do not appear to be available for the reliability of most of the detector systems. Table 3.12 shows an improving performance of residential smoke detectors, and it is assumed that the Building Warrant of Fitness requirements will result in regular maintenance and higher reliability of the other systems. Failures in the operation of sprinkler systems and their alarms are negligible. It is important to ensure, particularly for alterations involving existing sprinkler systems, that the installed system is appropriate for the proposed occupancy use.

One recurrent feature of failure of systems, noted over time, has been that buildings under alteration appear more susceptible to fire. Possibly because of 'hot' work activities, but also the detector/sprinkler system is disconnected during or as part of the alterations. Designers must take extra precautions where life safety may be involved, and may wish to consider additional care where protection of property only is involved.

The Acceptable Solutions have a range of requirements for the extent of the alarm operation. In some instances the requirement is to only warn the building occupants. For some installations the required condition is to provide an alarm to a continuously monitored centre, and in others to alarm direct to the NZFS.

5.10 NZFS Response

The response of the NZFS will initially depend upon the time taken for the alarm to be activated and the distance between the station and the fire site. Once an appliance has arrived at site the NZFS must assess the size and nature of the fire, the safety of those evacuated and possible assistance to any occupants remaining in the building, and any requirements for extra assistance. Generally connection of hoses to hydrant supply and fire fighting will only follow once all efforts to evacuate occupants have been exhausted. For design for Means of Escape designers must consider the likely delay for the NZFS to respond and undertake any rescue activities. Designers should not assume they will arrive in time to save people from the fire.

5.11 Summary

- * The characteristics of a detector system generally determines the effectiveness in its activation of means of escape;
- * The response of a detector will depend upon the type, size and rate of growth of a fire;
- * People close to a fire are generally better detectors than automatic systems;
- * Flame detectors are generally the most sensitive, but also most susceptible to activation by extraneous signals;
- * Smoke detectors are generally used as the earliest warning systems;
- * Sprinklers are a form of heat detector, with an in-built suppression system;
- * Automatic detection systems should be supplemented with manual call points;
- * All systems need to be connected to a warning/alarm;
- * Computer modeling needs to consider the possible options for the fire, and the activation of the detection system and alarm;
- * Where design is based upon a specific detector response, the relevant characteristics must be identified in the project specification;
- * Where specific properties are used in design calculations they must be specified into the construction documentation.

Chapter 6. Danger of Fire to Occupants

6.1 What is the Danger?

It is almost a rhetorical question to ask what is dangerous about fires? While there appear to be some obvious answers, when designing for the safe escape of building occupants from fire the specific dangers need to be identified.

Fires do not exist as a constant condition. It is usual to consider several phases - pre-ignition (smouldering), growth, developed and decay (Fig 6.1). Each phase extends over a period of time. Growth, developed and decay phases are all generally amenable to simulation/computer modeling (see below); however the pre-ignition phase is not so well defined and is largely dependent upon the actual source of ignition. Reliable computer simulation of this, pre-ignition, phase is not currently available.

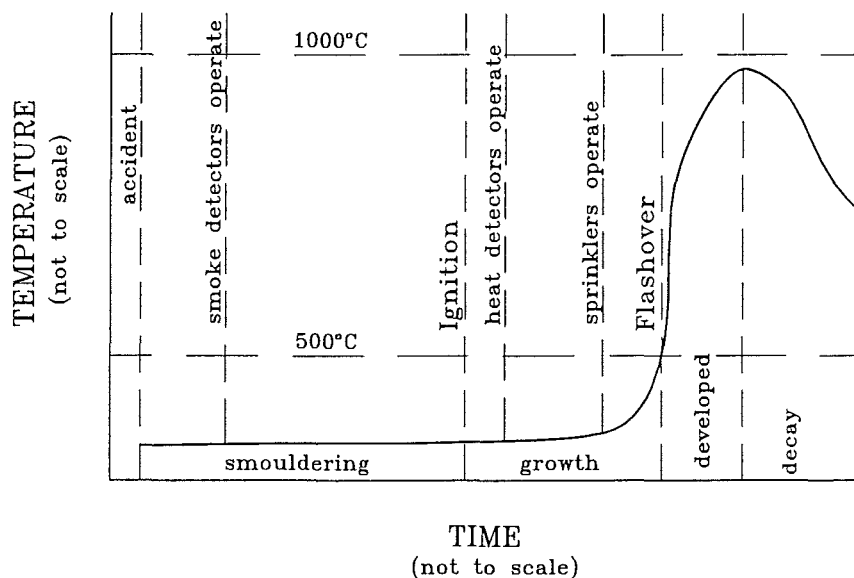


Fig 6.1 - Idealised course of fire (from Buchanan, 1994)

6.2 Basic Fire Conditions

There are three variations in basic fire conditions effecting occupants:-

- * smouldering;
- * small restricted ventilation fires; or
- * burning fires.

6.2.1 Smouldering Fires

Fires at the smouldering phase differ from the flaming (burning) phases in that they typically involve relatively low temperatures, but significant quantities of decomposition products (smoke). Purser (1995) notes that trials of smouldering furniture in a small apartment produced smoke down to floor level in 1hr. The concentration of CO in the burning room of the apartment would have been sufficient to cause incapacitation in this time. The rate of

evolution of these products in a smouldering fire is generally slow, and there is normally ample time for occupants to escape. However where occupants are asleep, under the influence of medication or alcohol, or are disabled they are likely to become victims, principally through CO narcosis. This condition has not been the subject of computer models with respect to tenability for occupants.

6.2.2 Small Restricted Ventilation Fires

In a closed room a flaming fire quickly uses up the oxygen, and as the oxygen concentration falls the burning becomes inefficient; producing a dense smoke rich in CO. This smoke and the reduced oxygen can rapidly produce untenable conditions, with potentially serious consequences for occupants (refer Section 6.3).

6.2.3 Burning Fires

Before Flashover a compartment in which there is a burning fire may be divided into four zones.

- the fire;
- the fire plume (ie immediately above the fire);
- the upper layer - containing the smoke and combustion products which spreads across the ceiling, and increases in depth with time; and
- the lower layer - below the upper layer, and supplies fresh air to the fire.

The immediate vicinity of the fire and the fire plume above are clearly considered untenable/fatal. Any person exposed in these zones will become involved or part of the fire.

The combustion products in the upper layer may include CO₂, CO, and HCN as well as smoke (C). There is also a significant decrease in the quantity of oxygen in the product stream.

The result of combustion on those exposed to the upper layer therefore may

- * be toxic (CO₂, CO, HCN);
- * obscure visibility (smoke); and
- * effect breathing (lowered oxygen) and irritants.

Purser (1995) also notes that the irritants may significantly effect the ability of occupants to escape.

After Flashover, the entire fire compartment is involved in the fire. The conditions after flashover are untenable, and will result in the death of any occupant in that compartment.

6.3 Room of Origin Deaths

Purser (1995) also reports that a 1981 UK pilot study in room of origin deaths of 19-49 year olds in dwelling/ textile fires showed the following probabilities. One fatality in over 23000 instances occurred where the fire was discovered in less than 5 minutes, whereas there was a one fatality for nearly every 300 instances where the fire had had the opportunity to develop for over 30 minutes before being discovered.

It appears most likely that the deaths occurring within 5 minutes of discovery were from rapidly growing fires (ie not smouldering phase) and the occupants either being involved (ie clothing alight) or attempting to extinguish. The ratio of fatalities at over 30 minutes is nearly 80 times that for under 5 minutes. Clearly the effects of delay in detection on the fatality figures indicate that safety of occupants is largely dependent upon early detection and warning.

While sleeping people may be woken by a sudden sound (eg broken glass or alarm) it appears that the body metabolism slowly adjusts to smoke conditions and fails to arouse/alert occupants (refer Chapter 8).

Two major points can be taken from the above -

1. The time involved through the smouldering, ignition and growth phases until detection is critical for escape.
2. Escape is concerned with those who may be subject to the effects of fire and can be evacuated, to a place of safety, before the conditions become untenable or fatal.

6.4 Designing for Fire

In considering escape from fire it is necessary to consider the danger being presented by the fire, with respect to time, in order to establish tenability conditions. This will require the designer to investigate the most likely and most serious scenarios. Factors involved include -

- * the time of day;
- * the location of the fire and the occupants;
- * the fire load;
- * the nature of the fire (smouldering or burning);
- * the rate of growth of the fire; and
- * limits on the fire size or development.

6.5 Timing and Location

The time of day may have some implications with respect to the potential fire. For example if at some specific time some particular "hot work" activity is undertaken, the risk may be higher. However timing is more likely to effect the number and location of occupants within a building. After normal working or opening hours security measures may result in limited egress for the (normally) reduced occupancy. The potential risk of fire to the occupants under out-of-hours conditions may need to be considered. One notable situation is the presence of a caretaker's apartment. In a factory or office building. Sleeping occupancy may be expected at night (and possibly during the day if the caretaker also acts as night-watchman), and allowance must be made for the alarming of and reactions by a person who may be asleep.

6.6 Fire Load

The Acceptable Solutions specifies design Fire Load Energy Densities (FLEDs) in terms of MJ/m² for Fire Hazard Category 1 to 3 purpose group occupancies. A Fire Hazard Category of 4 requires a specific assessment of the appropriate FLED.

Typical of these are:-

Fire Hazard Category	FLED Range MJ/m ²	Design FLED MJ/m ²	Typical Purpose Groups
1	0 - 500	400	hospitals, dwellings
2	501 - 1000	800	schools, retail shops, offices
3	1001- 1500	1200	bulk storage up to 3m high
4	>1500		supermarkets

Design for a specific occupancy FLED rather than the Acceptable Solutions specified default values may be appropriate also. The designer will need to substantiate the chosen values to the TA, and ensure that the owner is aware of the implications of changes in activity that may increase the FLED.

6.7 The Nature and the Rate of Growth of Fire

For Means of Escape two conditions were noted earlier as being most significant-

- * smoking/smouldering fires; and
- * burning fires.

These two conditions may follow in sequence; unfortunately there appears to be no computer model that provides for this situation. A smouldering fire may generate a significant quantity of smoke, before actually igniting. If the fire is not discovered until this latter point in time occupants may have to escape through a significant depth of smoke, that is then being increased more rapidly through the burning process.

For burning fires the computer models appear to generate smoke (and combustion products) in proportion to the rate of heat release. Therefore the faster the fire grows, and the higher the rate of heat release, the greater the quantity of smoke produced. This will increase the depth or thickness of the upper layer at a faster rate, and reduce the time available for occupants to escape before the layer descends to head height.

The design engineer will need to consider carefully the likely rate of growth, which to a large extent depends upon -

- * the nature and quantity of the combustible products; and
- * the distribution and layout of these combustibles.

Cooper (1995) discusses a semi-universal fire, which is similar, but not quite as rapid in growth as a Moderate Fire, and peaks at 10MW. Babrauskas (1995) also presents some data on burning rates for a very limited range of items. It is possible with some computer models to use this data in constructing a more realistic fire scenario for a particular situation. The Acceptable Solutions, where mechanical smoke control is required, specify 1.5MW fire size for purpose groups CS, CL, SC, SD, SA, SR, and WL and 7.0MW fire size for purpose groups CM, WD, and WM.

6.8 Ventilation

One factor that also requires consideration is the availability of ventilation, and the changes that may occur during the fire. Firecells may be partitioned with walls that have some integrity against fire; polycarbonate skylights may melt; doors may be wide open, ajar, or closed; and windows may be open, closed or break open if the temperature should rise sufficiently. The changing conditions may require to be modeled as they will effect -

- * the rate of burning;
- * the rate of heat output;
- * the spread of fire; and

- * the tenability conditions.

6.9 Limits on Fire Size and Development

A fire that is confined to only a rubbish bin may burn itself out before becoming a problem. Unfortunately fires are not always so confined; however the quantity of combustibles and/or the intervention of sprinkler systems may limit the actual size of the fire.

Notwithstanding that a fire may be shown (by the computer models) to be controlled by sprinkler activation it will still be necessary to show that occupants have a suitable margin of safety in their escape or continued presence in the fire compartment. One (generally assumed conservative) assumption is that the fire will continue to burn, from the time of sprinkler activation, with a zero growth rate. This will therefore still result in smoke and other combustion products for which tenability will need to be assessed.

6.10 Summary

- * Unsafe conditions are created by fire
- * Fires present occupants, as they escape, with a constantly varying environment;
- * Pre-flashover fire conditions may be considered in three basic forms -
 - smouldering; or
 - small, with restricted ventilation; or
 - burning.
- * Post-flashover fires are fatal for all occupants of the compartment.
- * Except in special circumstances the critical conditions for escape require consideration of -
 - smoke level - for breathing and visibility
 - heat - direct and radiation
- * Computer modeling of a fire requires assessment of the building and combustible parameters
- * Computer modeling of a fire is necessary to determine whether tenable conditions exist during the time required for occupants to escape

Chapter 7. Tenability Conditions

7.1 Introduction

While accurate assessment of the processes and products of combustion may be necessary for determination of causes of a fatality in the forensic situation (ie after the event), this is not normally the case in design for safe means of escape.

Tenability in fire conditions for escape may require consideration of -

- * heat - affecting the ability to breathe and producing burning of the skin or clothes;
- * visibility - affecting sight and recognition of escape routes;
- * toxicity - resulting in disabling of the senses and/or affecting the ability to breathe,
caused by increased CO₂, CO, HCN, or HCl or
caused by decreased O₂.

Individuals will respond differently to any one of these factors, and the response will also be dependent upon the duration and extent of exposure. A combination of factors may lower the limits producing disability below those for any one exposure factor.

Standard modeling of compartment fires is based around a two layer/zone condition. Computer calculations will define the interface level (height) between the upper and lower layers with an unreal mathematical precision. The physical reality is that the interface is not clearly defined because of turbulence and other factors not incorporated into the computer model.

Provided occupants can breathe relatively uncontaminated air and can see where they are going at all times during the evacuation process there is little risk of loss of life from the toxic products. This means that the level of the upper layer may not descend too low during the time taken for escape from the effected compartment. (If exceptionally toxic combustion products may be released because of the design occupancy conditions (eg in a chemical warehouse) then further special assessment of a safe exposure condition will need to be considered.)

Assessment of what constitutes a too low level needs to consider:-

- * the effect on the speed of escape when erect, bent double or crawling;
- * the 'fuzzy' definition of the real interface to the upper layer; and
- * the height of the occupants.

It is not reasonable to design for safe escape for other than erect occupants, as the speed of escape will be much greater than in the other positions.

While reliant upon design for an interface layer (without consideration of visibility, toxicity or temperature) it will be necessary to ensure that the interface layer is safely above the individuals exposed. The computer model exactness of the interface height does not address the reality of turbulence, mixing and entrainment which occurs at this interface. As a precaution it is recommended that an additional 0.1m allowance be incorporated into any computed interface level used in consideration of the interface layer height at the time that the last person leaves the effected space.

7.2 Heat Conditions

A person escaping from the fire may be moving away from the real heat source, but this may not mean that they are not exposed to excessive heat. The upper layer will consist of the heated combustion products, and these will radiate heat down to the occupants. Computer programs such as FPETOOL provide temperatures for the upper layer. In this context the upper layer temperature is a characteristic temperature. Temperatures near the ceiling will be hotter and temperatures near the bottom of the smoke layer will be cooler than the predicted temperature. This smoke layer will radiate heat down onto the heads, and bodies, of occupants.

It is possible to consider the situation of the upper layer and the head of an occupant (in the lower layer) as being similar to a plate radiating to a point on a parallel plate. If it is assumed that the computer given interface is at the upper layer temperature, and is a grey body radiating heat to a receptor at nominal room temperature, the radiant heat flux may be determined. This radiation, which is a function of the differences between the absolute temperatures each raised to the fourth power, will be conservative.

The head, being highest and therefore closest to the upper layer will be most effected. In a room situation the upper layer may be considered large in area compared to the distance from the layer to the head. This results in a relatively insensitive conditioning with respect to the radiation onto a persons head. It is necessary therefore to ensure that the intensity and time of exposure do not incapacitate the occupant. Drysdale (1985) indicates that 1 kW/m^2 may be received for an indefinite exposure period, but 6.4 kW/m^2 will be painful after only 8 seconds. Purser (1995) graphs the time for severe skin pain from radiant heat. For anything longer than 60 seconds this limit is 2.5 kW/m^2 ; and 5 kW/m^2 for only 10 seconds. Veghte (1982) notes an exposure of 21 kW/m^2 directly to bare skin results in pain and reversible injury after 2.3 seconds, and irreversible injury after 3.4 seconds. At 42 kW/m^2 the time to blister is about 1 second. The design for safe escape conditions must clearly avoid levels of exposure at these higher intensities, as escape will involve much longer times.

Bryan (1986) notes that without special protection -

- * skin burns at over 122°C
- * a 5 min tolerance to 141°C
- * the limit for evacuation is 150°C

Purser (1995) gives the time for incapacitation in air that is neither humid nor dry as -

$$t_{ih} = e^{5.1849 - 0.0273T} \text{ minutes}$$

For a 10 minute exposure this gives a maximum temperature (at head height) of $T=105^\circ\text{C}$. Custer and Meacham (1997) indicate that temperatures as low as 50°C produce severe discomfort and that teachers and school children could not be expected to enter a corridor in which the temperature was 65°C , and that death from hyperthermia occurs at temperatures above 100°C . Bryan (1986) noted tenability limits for residential occupancy dwellings as having a 5 minute tolerance time at 140°C .

It appears reasonable to accept for design that -

- * that people will not enter an area with a temperature over 65°C , and
- * at the point of escape into a safe path the maximum temperature at head height for those escaping should not exceed 100°C .

Computer programs appear to assume the lower layer temperatures are at ambient. The sensitivity of the temperature may need to be considered in any specific design calculations.

Convection is not normally a significant factor unless it is forced (ie by fan etc). Discussions with Fleischmann (Canterbury University lecture notes from Fire Dynamics) indicate convected powers at up to 0.025kW/m^2 for free convection and 0.01 to 0.5kW/m^2 for forced convection. A value of 0.25kW/m^2 from convection however should be included in the allowable exposures of 2.5kW/m^2 noted above.

Standards Australia (1996) provides limits as shown in Table 7.1.

Table 7.1

Limiting Conditions for Tenability Caused by Heat Radiation -	
$< 2.5\text{kW/m}^2$	$> 5\text{ min}$; and
2.5kW/m^2	30 sec

Characteristic exposure limits for Means of Escape are therefore recommended as-

- * 2.5kW/m^2 (comprising 0.25kW/m^2 from convection and 2.25kW/m^2 radiation) @ 215°C (max).

Assessment of the radiation may be calculated using the temperatures derived from FPETOOL or alternatively, CFAST provides for the defining of targets to report on the heat flux and temperature striking arbitrary positions and orientations. The use of a target at 1.7m close to the exit from a compartment should therefore provide a check on the radiated heat and temperature at head height against the time estimated at evacuation/departure from a compartment. The limits of 2.5kW/m^2 irrespective of time, and the temperature/time relationship (from Bryan) outlined above are recommended.

Because the design situation is time dependent, (and the rate of descent of the smoke layer is dependent upon the fire growth rate, ventilation and ceiling height) it is proposed that these are the maximum exposure rates at the end of the relevant time periods.

A more refined analysis can check the range of conditions that may produce untenability for occupants does not occur during the evacuation process. This requires using the analyses for the varying combustion products and checking the received dose against the time of exposure. Not only must occupants be able to breathe relatively uncontaminated air they must be able to see to escape.

7.3 Visibility Conditions

A simple requirement is to provide that occupants be able to see and to breathe uncontaminated air during the evacuation process. On this basis it is proposed that for safety under normal circumstances the interface layer should not descend below eye height for the 95%ile, together with the 0.1m margin noted previously.

Tutt & Adler (1981) give eye height for the 95%ile male aged between 18 and 40 as 1742mm . This level is conservative on the overall population, and so an eye height of 1.7m plus the 0.1m "fuzzy" margin gives a recommended design level for the interface as 1.8m . This may be compared to crawl clearance height which is given as 0.8m . Depending upon the rate of descent of the interface there may be time for persons to escape by crawling. This is not considered (by the writer) as being safe practice, and should therefore never be relied upon for safe escape.

Alternatively it is possible to estimate the actual visibility conditions along the travel route with respect to time (again the critical points will be at exits from one space into another).

Visibility distance limits proposed (Purser, 1995) are shown in Table 7.2.

Table 7.2

	smoke obscuration OD/m	extinction coefficient $K=2.3 \cdot OD/m$	visibility distance Sv (m)	
Jin	0.06	0.15		unfamiliar
Jin	0.2	0.5		familiar
Rasbash	0.08	0.3	10	
Babrauskas	0.5	1.2	2.6	familiar

Purser (1995) does not develop any relationship between visibility distance and smoke obscuration. Standards Australia (1996) however provide a series of relationships and Tenability Limits where -

$$\begin{aligned} \text{Optical density/unit length, } DL &= (-\log_{10}(l/l_0))/L \text{ in units } m^{-1}, \text{ where} \\ l &= \text{intensity of light with smoke; and} \\ l_0 &= \text{intensity of light without smoke; and} \\ l/l_0 &= \exp(-kCL); \text{ where} \\ k &= \text{absorption coefficient of smoke} \\ C &= \text{mass concentration of smoke; and} \\ L &= \text{path length of the optical beam.} \end{aligned}$$

Another popular expression for optical density/unit length, or obscuration is -

$$OD = (-10 \log_{10}(l/l_0))/L \text{ in units db/m-}$$

such that visibility can be related to obscuration with-

$$1 \text{ db/m} = 10 \text{ m visibility,}$$

and lastly the percent obscuration of smoke (OB) may be defined by-

$$OB = 100(l_0 - l)/(Ll_0)$$

Using these criteria the Standards Australia (1996) sets Tenability Limit for Smoke Obscuration dependent upon the room size are shown in Table 7.3.

There are clearly some differences in these two systems, and their recommendations - which need to be resolved. It is the writer's opinion that the Fire Engineering Guidelines distance limits appear reasonable and are therefore recommended as design criteria.

Table 7.3

Location	Equivalent Optical Density (m^{-1})	Equivalent Optical Density (db/m)	Minimum Visibility Sv (m)
Small Rooms	0.2	2.0	5
Other rooms and spaces	0.1	1.0	10

7.4 Movement Through Smoke

Canter (1990a) and Donald and Canter (1990) noted in the responses to a survey of 252 persons with respect to escape from fire as -

No smoke	86	
Some smoke	94)	
Thick smoke	52)	167
Very thick smoke	21)	

With respect to ease of exit;

Some	Smoke		Difficulty of Exit		
	Thick	Very Thick	None	Some	Much
94			92	2	
	52		27	24	1
		21	6	8	7

Clearly the presence of some smoke has little effect on the difficulty of escape, and even thick smoke was found to only effect the ease of escape of 50% of that population. Canter indicates that "moderate" smoke is likely to be associated with no difficulty. However once smoke is classified as "thick" the great majority of people are likely to describe egress as being with some difficulty. The density of smoke that relates to the descriptions is not given by Canter. The responses were from a survey, and apparently based on the perception of the respondents. The recommendations given for smoke levels and visibility distances therefore may be conservative. The alternative, is to design for smoke at 1.8m above floor level as noted above.

7.5 Toxicity

Carbon monoxide (CO) poisoning is the most common factor in fire fatalities. A measure of its toxicity is - the exposure concentration C (ppm) multiplied by the exposure time t_c (min).

The toxicity level is lower for subjects with cardiac conditions. Custer and Meacham (1997) provide a table as a guide, and Purser (1995) has more comprehensive information.

Some computer programs provide the proportion of Carbon Monoxide as a percentage.

As an initial guide it is recommended that the characteristic values-

$$C.t_c = 6000; \text{ or } \text{ of } 1\% \text{ for } 5 \text{ minutes}$$

should not be exceeded without further analysis of the dangers.

Carbon dioxide (CO₂) is universally present in fires - and because of the effects of increased levels on breathing it is recommended that the characteristic levels should not exceed 3% for 5 minutes without further investigation.

Hydrogen Cyanide (HCN) has been associated with fires as a cause of incapacitation, and may be produced most significantly in burning of acrylics, polyurethane foams, melamine, nylon and wool. The proportions of HCN are increased even further in post-flashover fires - but it is unlikely that Means of Escape will be under consideration at that point in time. A characteristic limit of 75ppm should not be considered without further investigation of this hazard.

Oxygen depletion is a consequence of burning, and even slight depletion levels effect physiological performance. Individual responses are effected by such factors such as age and overall condition. Characteristic exposure conditions of less than 17.5% of O₂, for up to 60 minutes, or 15% for any time are not recommended without further investigation.

7.6 Occupancy Conditions

The above conditions for escape are all based upon the occupant being awake and alert to be able to escape. It also assumes that basically a burning fire condition exists rather than a smouldering fire. Because a smouldering fire will result effectively in more smoke than heat provided the escape can be undertaken below the smoke layer the tenability conditions will normally be satisfied. The response by individuals to fire and alarms under a variety of situations, including sleep, will be discussed later.

Studies of the behaviour of individuals in fire incidents indicates that familiarity with the surroundings, including exit routes and places of refuge is a significant determinant on the willingness of occupants to move through smoke (Bryan - 1986.). In residential fire incidents 46% of occupants were found to have moved more than the visibility distance through smoke:

- 35% the distance equal to the visibility distance; while
- only 18% moved less than the visibility distance.

It was found that over 50% of residents only turned back/ceased to advance through smoke when visibility distances were reduced to less than 2m.

Design for such limited distances is not considered reasonable with 5m recommended as more appropriate when:

- * occupants are familiar with the surroundings
- * the visibility limit is only reached at the time of exiting the compartment

7.7 Computer Models

Where computer models indicate that the interface layer is over 1.8m above the floor at the time the last person exits from the effected space it is generally reasonable to assume conditions are safe.

Computer models need to be used with care. Design for smoke levels below 1.8m height above the floor and should show that up until the time of exiting a compartment -

- * visibility is within acceptable limits;
- * atmospheric gases are within tenable limits; and
- * the temperature is within acceptable limits.

FPETOOL in its FIRESIMULATOR routine provides a model for visibility and air condition. FIRECALC also provides air condition and visibility (including for smouldering fires) but uses different criteria to FPETOOL.

7.8 Safety Margin

These characteristic values do not include a margin for safety. In the design for escape it may be reasonable to consider a margin for safety, either in terms of time or a more conservative proportion of the gaseous hazard.

Purser notes that the exposure to the various hazards are be cumulative. In the first instance it is recommended that the sum of the ratios of each of these gases to the selected values should not exceed 1.0 Refer further to Purser (1995) for calculations of the fractional equivalent dose where there is a combination that is subject to concern.

Behaviour responses are discussed in more detail in Chapters 8 and 10.

7.9 Safety by Separation

The most significant factors in the providing safety of occupants is separation of the occupants from the fire and smoke. Occupants may leave the area of the fire. Walls, closed doors and windows will in the first instance prevent the spread of smoke and other combustion products, and provide time for escape to a safe place. (This form of separation is regarded as a protected path by the Acceptable Solutions.) The writer is concerned that the quickly growing fires may develop sufficient smoke to effect the escape of occupants on intermediate floors, particularly where there is limited height or smoke reservoir.

Once a fire becomes fully developed, unless the size is limited, the heat and/or smoke will be sufficient to overcome occupants of the firecell.

7.10 Intermediate Floors

Intermediate floors are basically upper floors in a firecell that do not form a firecell in their own right. An Intermediate floor may have a smoke separating partition (glazing or solid, non-fire rated partition) from, or it may be open to, the balance of the firecell (as may occur with a balcony in a theatre or atrium). Often the height available between the Intermediate floor and the ceiling is relatively limited. Because smoke rises the occupants of an open intermediate floor are most likely to be the first effected in a fire. It has been found by the writer, in several practical design situations, when given even reasonable response times for detection, investigation and movement that even a fire with Moderate growth rate may generate sufficient smoke to create untenable conditions before occupants would be able to escape.

The Acceptable Solutions permits Intermediate floors without a smoke reservoir, mechanical ventilation or other specific attention to the problems of smoke. It is the opinion of the writer that all Intermediate floors need to be considered with care because of their potential hazardous conditions

7.11 Summary

- * Tenability conditions need to be established with consideration of the occupants and the likely nature of the fire and combustibles. Some of these conditions follow:-
- * Except in special circumstances a smoke level 1.8m or more above the escape route may be considered safe for escape; alternatively where lower smoke levels are unavoidable minimum visibility limits (for well mixed smoke) are recommended as 5m for a small room, and 10m for larger spaces.
- * Characteristic tenable heat conditions are- 2.5kW radiation from the upper layer (of maximum temp 215°C) and the lower layer temperatures are-

<65°C at the point of entry into any path/area; and
<100°C at the point of leaving the affected area.

- * a maximum time of travel movement should not exceed 8 minutes to exit the premises.
- * Consideration is also required of characteristic tenable limits for CO, CO₂, HCN and O₂.

Recommended individual limits are -

CO	- 6000ppm.min or 1% for 5 min;
CO ₂	- 5% for 5 mins;
HCN	- 75ppm;
O ₂	- 17.5% for 60mins, 15% minimum

- * Combination of conditions should be less than the Fractional Equivalent Dose.
- * Separation by distance provides the safest solution.

Chapter 8. Responses to Fire

8.1 General

The design for safe escape needs to consider the likely responses of building occupants in fire situations. It is only by this process can a designer ensure that adequate and sufficient provisions are made. There has been little study in New Zealand, but some significant research has been undertaken in the UK and the USA.

8.2 Awareness Cues

Surveys were undertaken by Wood (1972) of 2193 people involved in 952 fire incidents in the UK, and Bryan (1977) of 584 people in 335 incidents, and Bryan and Milke (1981) of 150 people in 59 incidents. One focus of these studies (which are relevant to several areas of the investigation) was the means of awareness of the fire incident for the participants. Table 8.1 shows the results of these three studies.

Table 8.1 Means of Awareness - % of participants

Means of Awareness	Wood	Bryan	Bryan & Milke
Heard alarm bells		7	22.7
Heard PA announcement	)		18.6
Informed by other staff	) 23	) 34.7	26.0
Informed by patient	)	)	7.3
Heard noises	8	18.6	
Heard Screams	11		1.3
Smelled smoke	) 33	26.0	12.7
Saw smoke	)	9.1	6.0
Saw fire	15	8.1	4.0
Saw burn marks			0.7
Saw water			0.7
Felt Heat	1	0.7	
Explosion		1.1	
Saw or heard fire appliances		0.7	
Other	2	1.0	

Bryan (1983) concludes that the means of stimulus providing the awareness of building occupants is determined significantly by the occupancy of the structure and the installation of fire alerting devices. Apartment and office buildings and health care facilities are most likely to be required to have alarm systems. Single family dwellings are exempted from most fire alarm system requirements. In the USA the frequency of installation of smoke detectors in dwellings was found to be much greater than in the UK. In NZ, despite the recent publicity in the media, and the NZFS community support programmes in some areas it is the writer's opinion that smoke detector installation in dwellings is still much less than the 42.8% in the survey sample (in 1977). One point of concern was the reported 28.7% of operation of these detectors. Bryan (1977) does not indicate whether this was through malfunction, earlier awareness than given by the detector or the fire being too remote. The NZFS statistics (Table 3.12) indicate that in an average of nearly 15% of instances the domestic smoke detectors failed to provide a warning. Clearly the installation and maintenance of smoke

detectors will provide early warning in many instances, and save lives. Reliability of their performance to match that of sprinkler systems is desirable.

Bryan (1977) noted that approximately 40% of the population were within 3m of the fire incident and over 80% were within 9m when they became aware of the occurrence. Wood (1972) presented similar figures. Given the size of a dwelling unit it is not surprising since most individuals surveyed by Wood were in the unit of fire origin. In health institutions (Bryan and Milke, 1981) only 34% of the study population were found to be within 9m of the fire incident.

The real significance of the distance from the fire incident at the time of awareness is on the method of awareness. Bryan (1983) notes that persons within 6m were alerted by means of awareness of:-

- * smelled smoke;
- * saw smoke;
- * saw fire

whereas those more distant were alerted by:-

- * heard alarm bells;
- * heard pa announcements.

The awareness of the fire incident is seen therefore to arise from a cue, hearing, seeing, smelling etc as noted above. The responses to the cue may result in a variety of responses.

8.3 Initial Responses

Comparisons of first actions as found by Wood (1972) and Bryan (1977) are as in Table 8.2.

Table 8.2 Comparison of First Actions - UK and USA

Actions	Wood (UK) %	Bryan (USA) %
Notified others	8.1	15.0
Searched for Fire	12.2	10.1
Called fire Dept	10.1	9.0
Got Dressed	2.2	8.1
Left Building	8.0	7.6
Got Family	5.4	7.6
Fought Fire	14.9	10.4
Left Area	1.8	4.3
Nothing	2.1	2.7
Had others call FD	2.8	2.2
Got Personal Property	1.2	2.1
Went to Fire Area	5.6	2.1
Removed Fuel	1.2	1.7
Entered Building	0.1	1.6
tried to Exit	1.6	1.6
Closed Door to Fire Area	3.1	1.0
Pulled Fire Alarm	2.7	0.9
Turned off Appliances	4.1	0.9
Number of participants	2193	580

Also of interest is Table 8.3 where Wood (1972) considers the first action by Building Category. There we can see that fire fighting and evacuation of the building ranked almost equal in the family dwelling situation. These were also nearly the same as the proportion of those whose first action was to investigate. This data would appear to reflect the conditions, for the former, where the fire required no investigation and the responses largely of the adult respondents, and in the latter where the actual presence of fire required to be confirmed. In the other building categories, fire fighting was more 'popular' as a first action than investigation. This may reflect the incidence of alarms from detection systems and organised drills for fighting fires.

Table 8.3 Building by First Actions

	<u>Building</u>			<u>Category</u>		<u>Instit</u>	<u>Retail</u>
	<u>Home</u>			<u>Work</u>			
	Dwell	Flats	Multi	Factory	Ware	Hosp'l	Shops
			occ'y		house	School	Pub
					Garage	College	Cafe
						Hostel	
<u>First Actions</u>	%	%	%	%	%	%	%
Investigate	12	12	17	12	8	15	10
Called FireDept	9	12	12	7	13	7	16
Move away fire	2	3	3	1	1	3	2
Move towards fire	5	4	8	7	11	7	1
Warn others	8	9	20	6	4	7	6
Move toward exit	1	3	3	1	2	1	2
Left Building	8	6	6	7	17	7	8
Fire Fighting	10	12	6	23	14	12	20
Minimise risk	1	0	0	9	2	2	2
Save effects	0	0	3	1	4	3	1
Raise Alarm	0	0	1	7	3		1
Organise evacuation	1	3	1	1	3	5	3
Request help	3	1	1	2	2	1	3
Give help	1	1	3	2	1	2	2
Await rescue	0	0	0	0	0	0	0
Re - entered	0	0	0	0	0	0	0
Switched off mains	6	4	2	1	1	2	2
Contacted Authority	1	1	0	4	5	4	3
Shut doors	6	3	3	0	0	2	1
Evacuate family	11	11	2	0	1	2	1
Move burning object	2	2	1	0	1	2	0
Get dressed	3	4	4	1	1	3	0
Assist fire Brigade	0	0	0	0	0	0	0
Enquire if FB called	3	3	2	2	1	0	4
Move to a safe place	0	2	1	1	1	1	1
Cover face with cloth	0	0	0	0	0	2	0
Inaction	1	1	1	4	5	5	2

Wood (1972) noted some differences also in First Actions between those in the 'home' environment and a secondary group occurring in hotels. It can be seen from Table 8.3 that for those at home a smaller percentage called the Fire Brigade or fought fire, whilst a larger percentage investigated, warned others, tried to save effects and moved towards the exit. It was only in this last action however was there a significant difference under statistical analysis.

Bryan & Milke (1981) did not provide the same options for participants in their survey. However a summary of the 1st, 2nd and 3rd actions (Table 8.4) of the participant population is instructive.

Table 8.4 Summary of Actions - Project People II (Health Care)

<u>Actions</u>	1st Action %	2nd Action %	3rd Action %
Investigated cues	45.0	6.6	2.9
Closed Doors	14.1	10.3	9.6
Rescued Threatened Patients	6.7	5.9	2.9
Discovered Fire	6.7	8.8	0.0
Pulled Manual Fire Alarm	5.4	6.6	2.9
Evacuated Patients	4.7	19.3	35.7
Attempted Extinguishment	4.0	9.6	15.4
Got Extinguisher	4.0	4.4	3.8
Instructed Operations	3.4	0.7	1.9
Phoned Operator	2.7	5.1	4.8
Ventilated	1.3	0.7	1.9
Alerted Other Staff	1.3	4.4	3.8
Called Fire Dept	0.7	8.8	5.8
Stood By	0.0	5.9	4.8
Attempted Rescue	0.0	2.2	3.8
Performed 1st Aid	0.0	0.7	0.0
Number of responses	149	136	104
% of survey population	99.3	90.7	69.3

There is clearly a real message given in that for many the first actions are to seek confirmation of the cue and/or attempt to manage the fire.

It is also important to note that these surveys result from fires attended by the relevant fire brigade services. There will be many other instances where fires have been detected and extinguished without recourse to calling the brigade for assistance, and without injury to the occupants.

8.4 Response to Alarms

Custer and Meacham (1997) provide some interesting data on the delay times to the start of evacuation in apartment buildings -

- * most occupants evacuated in groups, with the speed of the slowest person setting the speed for the entire group;
- * it took 25 minutes to evacuate a building where the alarm was inaudible, compared to 13 minutes where it was audible; and

- * where the alarm was judged loud enough by more than 80% of the occupants to be heard the mean time to start evacuation was 2.75 minutes, compared to 9.03 minutes where the audibility was poor.

8.5 Design Response Criteria

The question therefore arises, what actions should be considered and included in the design for safe escape?

From the preceding sections it can be seen that there are some strong indications of responses to people to fire cues. It may be appropriate to also consider the training that may be appropriate which will increase safety of occupants.

The factors which are identified as significant are-

- * the distance from the fire;
- * the form of the cue received;
- * the personal situation;
- * the presence of others; or
- * the situation of others

Canter (1990a) notes that pre-fire activity is an important factor in predicting subsequent actions, and may even influence the type of cue received and the readiness with which people react. The smell of burning toast in a restaurant is unlikely to invoke an emergency response from the patrons unless a warning is given by the staff. In domestic fires if the female receives the cue and investigates, the male when subsequently told is likely to also 'have a look' and delay further action.

8.5.1 Occupants Close to Fire

Occupants who are close to a fire generally receive the first cue from the fire itself (smoke, smell, flames, heat, sound). The most common response is for occupants to investigate and/or attempt to extinguish the fire. The 2nd action was to alert others and/or call the fire brigade. In dwellings evacuation of the family ranked similar to calling the fire brigade. In Health Care facilities the evacuation of patients ranked ahead of calling the fire brigade. Bryan (1983) noted that closing doors ranked significantly in the response actions. These occupants are by definition close to the fire, and probably in the same firecell. The time taken to respond and to move to safety is critical.

Investigating a cue to confirm the presence of a fire can be expected, after all the burning smell may only be toast, or the iron scorching the ironing cover. However it has been noted that a number of fatalities occur through attempts to extinguish fires. This appears to be because most people have been found to be a poor judge of the rate of growth of a fire and the serious threat it may pose. Attempts to extinguish should not be encouraged even in smouldering or the smallest of flaming fires. Closing the doors to control the spread of flame and smoke will provide additional time for escape of occupants and potential for control by those equipped for the task. It is the writer's opinion that this is a lesson that should be promoted through the schools and the media similar to the "drop and roll", "feel the door temperature" and "the air is better near the floor" television promotions of the 1970's and 1980's.

Egress of occupants effectively begins from the time the first cue is received. As noted, some investigation can be anticipated. It is probably reasonable to assume that the recognition of a cue and a confirmatory investigation will take possibly 2 minutes. This is sufficient time for a single person to walk nearly 50m along a horizontal path, ie enough time

to generally walk around a house and look into each room. Each situation however will need to be considered on its own merits.

If a fire is confirmed, others probably need to be alerted and possibly the fire service called. People who are awake and dressed may gather some effects and be ready to move in less than 30 seconds. However if occupants are asleep and/or consider they need additional clothes and to gather effects, they will take longer. Pauls (1995) notes that in office buildings there is normally a 41 second time from the decision to move for flows to attain mean rates. It is recommended that this be used as the response time t_r , and be incorporated into the escape time for offices and where people will be awake. Longer times will be needed for sleeping occupants; with probably over 2 minutes being required for those under the influence of medication or drugs (from the time of arousal).

The failure in early detection and effective warning systems has been found as a common feature in many major disasters. Often, where fire was detected at an early stage attempts were made to extinguish rather than to instruct people to leave while the fire was still small (Purser, 1995).

Recent fatalities in fires in New Zealand have largely involved either children, elderly (disabled or effected by drugs) or sleeping occupants. Experience has shown that Rest Homes providing care for the elderly, who may be less mobile and possibly also under medication require particular attention to their safety and evacuation. The ability of staff to access, rouse and manage with a number of people needs to be considered in the design for safe escape.

It is an unfortunate fact that children are attracted to playing with fire (matches, lighters, candles etc), and unaware of the dangers, which results in a fire rapidly growing out of control in their compartment. The sleep of children also appears to be less disturbed by outside influences (alarms, shouts etc) (Grace, 1997), and so may be at risk from fires elsewhere in the house. Because single family dwellings are generally exempt from fire safety design these problems may only arise in some special circumstances with respect to design for means of escape.

Therefore the time required from a confirmed alarm to moving-out could be well in excess of 1 minute. It will be necessary to consider each situation on its merits. Calling the fire service by telephone, must be considered secondary to moving to safety, and need not be included in the time considerations.

8.5.2 Occupants Remote From Fire

Occupants who are in a separate firecell or in some other safe place may be regarded as 'remote' from the fire. In these situations the cue received is normally from some system device, alarm bell or PA etc. There may be some investigation, and fire fighting if the fire is found to be relatively close (eg in the adjacent firecell). Particularly if there is no other cue the more common response appears to be evacuation, after gathering belongings etc. Clearly if the escape route requires travel through smoke or close to the fire then the time for response and travel movement may be critical. The reliability of the cue is important to its recognition and response. The degree of commitment of occupants to their current activity also needs to be recognised. The final stages of a complicated negotiation may be continued, or sleepers may not wish to ignore the signals. Additional and reliable cues, from fire wardens or similar, may be required to ensure evacuation until the situation can be confirmed as safe.

8.5.3 Occupants Adjacent to Fire

Occupants in the firecell may be separated from the effects of fire by-

- * distance; and/or
- * non rated walls, doors partitions, ceilings etc.

The fire cue may be received from -

- * an automatic detector and alarm system;
- * an oral warning by others closer to the fire;
- * the growing fire effects directly; or
- * an oral warning from other external source.

An analysis may be made for various fire scenario and the relevant detector/alarm systems with allowance for the time for verification, preparation for movement and actual escape to a safety. It is required to show that in the time taken to reach safety conditions have not become untenable.

Where the occupants receive an oral warning from others in the firecell a similar analysis can be carried out.

Because of the separation from the fire it may have grown to a considerable size before direct cues are received/noticed by adjacent occupants. Similarly the fire may be sizeable before occupants external to the fire take notice and provide warning.

Fires grow dramatically with time, and the later the warning the larger the fire is likely to be, with the associated increase in danger to the occupants.

8.5.4 Commitment to Action

In these situations the response to the fire cue is particularly relevant in the timing for escape: it (the reaction) may depend upon the social interaction (Bickman *et al*, 1997) and abilities of those present. Where there is a single individual or a group with a leader or senior person present (where attention may be drawn to the cue) then some investigation into the cue can be expected. For a group where there is no clear leader or authority a delay may result because no single individual is prepared to take the lead. This delay may continue until the cue can not be ignored. Investigation may still occur, but the fire will have further grown in size. It is probably reasonable to assume that under these conditions the acceptance of the cue and a confirmatory investigation will take possibly 30 seconds.

Again the degree of commitment of occupants to their current activity also needs to be recognised. Patrons in a restaurant may not distinguish a burning smell from the kitchen, particularly if the staff do not take any action to warn them; and shoppers in a supermarket check-out queue will be committed to paying for their trundler of goods and taking it with them, rather than leaving it behind, unless the check-out operator takes appropriate action.

In designing for safe escape the size of the fire at the time of cue acceptance will need to be considered. The warning to others and the move-out time will need to be estimated with respect to the general circumstances, but it may be reasonably assumed that the warning message would indicate the severity of the situation. Fire fighting is unlikely to be a viable option except by trained persons and can be regarded as being an unsafe option in designing for escape.

8.5.5 Alternative Alarm Cues

Voice communication systems that permit warnings or instructions over a public address system appear to be an excellent method to provide both a cue to occupants but also instructions on the required evacuation procedures. Each system will need to be tailored for

the relevant purpose group or situation, as it appears likely that a standard pre-recorded message will be appropriate in only few situations.

For cinemas a displayed message onto the screen may also encourage the evacuation of patrons in an orderly fashion.

The position may be particularly critical if there is only a single means of escape and the route is past the fire compartment or area. The approach of the Acceptable Solutions does not consider the danger of this situation except by way of a shorter travel path (the travel time is reduced to 1 minute).

8.6 Responses to Alarms/Cues

The response to the cues may depend upon-

- * the audibility of the signal
- * recognition of the alarm signal; and
- * the perceived reliability of the warning 'device'.

The metabolism of sleeping occupants will slowly adjust to the presence of smoke, and may result in the gradual suffocation of the occupant rather than arousal and escape. The breaking of glass or activation of an alarm sounder at a sufficiently early stage may be sufficient trigger to wake the occupant, who if not too effected by the smoke may be able to escape.

An automatic detector or a manual operated call point will generally result in activation of an alarm sounder. While those who are close to a sounder device may complain at the excessive sound the designer must ensure that all occupants will hear the alarm. This may require additional sounders to ensure that all occupants will hear the alarm without deafening those close to the sounder, and ensure that in some areas/occupants will hear the alarm despite closed doors or extraneous noise in the premises. This will also reduce the risk of close occupants taking action to muffle the alarm. The Acceptable Solutions requires sounders to all sleeping areas in certain occupancy groups, and this appears to be a reasonable precaution.

Grace (1997) noted the variability in alarm sounder signals, and the potential confusion that may arise through non-recognition. Similarly, where warning is given orally, unless the warning is perceived as reliable, occupants may not respond, or may go and investigate so as to confirm the situation.

The likely presence of hard of hearing occupants may need to be recognised, and in these instances a strobe light system may need to be installed. In commercial occupancies providing sleeping accommodation this may require management to ensure that clients are aware of the availability of the relevant systems, and to assign them appropriately.

Systems with frequent false alarms may be ignored by occupants because of their perceived lack of credibility as a warning system. Delays in acceptance of the cue however may mean that the fire can grow in size and potential hazard to the occupants. In NZ the Building Regulations (NZ Govt 1992) require regular testing of alarms and twice yearly evacuation drills. These are seen by the writer to provide an environment that should encourage -

- * familiarity with the alarm/warning signal for regular occupants, who would be expected to advise visitors of the situation;
- * ensure reliability of the system (regular, but not over tested systems), and so reduce false/vexatious alarms; and
- * awareness of the egress routes and procedures for regular occupants.

It needs to be noted that where premises are not continuously occupied, or are occupied by different groups during the normal course of events (eg churches and church halls), special attention may need to be taken to ensure recognition of alarm cues, the abilities of occupants present and the means of escape.

Even when a potential cue is recognised, it is quite usual for its reliability to be verified (by investigation or otherwise) before taking any further action. That further action may (as noted by Wood, Bryan, Bryan and Milke) take the form of -

- * fire fighting;
- * warning others (orally or by alarm);
- * calling the fire brigade;
- * closing doors;
- * 'packing up';
- * helping others to escape; or
- * evacuation.

The decision of appropriate actions will generally depend upon how serious the fire condition is perceived, the role of the individual in the premises concerned and the personal capabilities of the individual.

A personal observation by the writer of the time for response to (unannounced fire drill) sounder cues has been, 15 seconds, to assess that it is an alarm cue, not a check of the sounder; and then 45 seconds to turn off computers, gather jackets etc, and the last person to move 30m to the exit door, for an office with approximately 20 staff, and no queuing at the egress.

The time likely to be involved may vary considerably for the above actions. Buchanan (1994) indicates that 0.5 minutes should be allowed for the packing up and closing doors option. Where assistance in evacuation is required (eg in rest-homes for the elderly, sleeping or disabled), the designer will need to consider the capabilities of all those involved. The time required for waking and assisting even a single patient may take over 2 minutes, and the speed of movement of the patient and helper will need to be carefully assessed.

The provision of appropriate means of escape should ensure sufficient warning and travel paths that will not result in occurrence of panic. (Panic may be assumed as maladaptive behaviour or behaviour contrary to the interests of others, arising from a fear of a real or supposed danger). Reports by Wood, Bryan & Milke of inaction as first actions may be construed as either panic (being frozen or scared to inaction), inability to do anything (likely if disabled) or being blasé and ignoring the cue altogether. There is insufficient data to determine the numbers (if any) of inaction responses that could really be classed as panic. In practice actual panic has seldom been reported except where early cues have been ignored, travel routes have been blocked or heavy (black) smoke filled the firecell. (Bryan, 1958).

8.7 Delay in Warning Cues

The only recognition of the effect of timing of warning cues in the Acceptable Solutions is the increased lengths of travel paths for heat detectors (15%), sprinklers (50%) and smoke detectors (100%). Because the basic Total Open Path has been related to 2.5 minutes of travel time, it at first appears that the time for warning is related in proportion to the above increases in the travel paths. Computer models however rarely show such correlation between the action of the detector system and the time for tenability.

However, at least there is a basis for the calculation of the time for travel given that the fire growth and tenability conditions can be related to that point in time at which the warning cue is given.

The real problem is at just what point in time can it be expected that a building occupant will recognise the presence of a fire if there are no installed warning systems.

8.8 NZFS Response

Design that requires the NZFS intervention or action to assist with evacuation of building occupants must recognise the significant delays that will arise through -

- * time to activate alarm;
- * time to alert brigade;
- * response time for appliance to leave fire station;
- * travel time to site;
- * time to establish fire scenario upon arrival;
- * time to enter building and affect any required assistance.

Clearly the elapsed time before the last step will be of the order of 10 minutes (or more) and will therefore require the occupants to be removed from the fire area into a “refuge area” or a “safe path” if they are not to be exposed to untenable conditions.

8.9 Response Processes

A flow chart (Figure 8.1) is provided to show the processes in the response of occupants to alarms/cues. The chart follows the steps that may be taken by occupants from the acknowledged time of receipt of a warning cue, but without considering the effects of time. There may be a direct cue, from or of the fire itself (ie occupant can see the flames) or from another warning eg automatic alarm or oral warning. Ignoring the cue or not responding is likely to be unsafe, and effectively returns the occupant to the ‘START’. Choices or action that may effect the course of the fire (eg extinguishment or closing doors) or the action of others (eg oral warning to others or alarm activation) are shown. The identification of the relevant response actions is necessary for the estimation of the time that will be taken to escape to safety, from that time at which the initial cue is received.

Activities such as get dressed, pack-up etc are not shown, but if and/or where they occur time will be involved in the escape process. The flow chart assumes sufficiently early warning to allow the processes to be followed and clearly identifies actions that may be potentially unsafe.

Safety depends upon timely receipt, recognition and response to cue(s).

The chart includes provision for attempts to extinguish or otherwise modify the fire (eg remove fire from source). Such close involvement with a fire is potentially dangerous, particularly if the occupants are untrained. Alarm activation and evacuation is recommended as generally being the safer course of action.

Note that this ‘event tree’ could be used as a basis for probabalistic assessment of fire safety, with probabilities attached to the Yes/No outcomes of each action. This approach however is beyond the scope of this project.

8.10 Summary

Occupants may be either:-

- * close to the fire; or
- * remote from the fire; or
- * adjacent to the fire.

Those close to the fire are likely to receive cues direct from the fire and:

- * some investigation may take ;
- * fire fighting may take place;
- * warning others and evacuation are essential for escape.

Those remote from the fire are likely to receive cues from a warning system or message. Because of the indirect nature of the cue source and desire for confirmation delays are not uncommon in commencing evacuation, but the separation distance from the fire generally means this is seldom critical, but must be confirmed.

Occupants adjacent to the fire may be most effected by -

- * delays in receiving and confirming cues;
- * investigation;
- * travel routes past the fire area.

Alarm systems must be audible to all area and need to be recognised -

- * as a warning;
- * as reliable; and
- * requiring prompt evacuation.

Occupant response may depend upon the commitment to an activity or within a social group at the time of receipt of a fire cue.

Strobes or some other warning light system may be required for those hard of hearing.

Chapter 9. Physical Conditions of the Firecell and Escape Routes

9.1 General

The failure in early detection and effective warning systems has been found as a common feature in many major disasters. Often, where fire was detected at an early stage attempts were made to extinguish rather than to instruct people to leave while the fire was still small (Purser, 1995). It has been shown (Canter, 1990b) that many people underestimate the rate of growth of a burning fire. The fatalities noted above may be examples of faulty assessment.

Two major points need to be considered in providing safety of building occupants -

1. The time involved in the smouldering, ignition, growth phases until detection is often critical for safe escape.
2. Escape is concerned with ensuring those who may be affected by the effects of fire can be evacuated, to a place of safety, before the conditions become untenable/fatal.

The design of an escape system presents basic problems in four dimensions; the relative position of any particular building occupant in space (three dimensions) with the passage of time (the fourth dimension). This information must then be related to the tenability conditions, with respect to time at the positions as occupied by the occupant. It is common to consider a time line to plot the actions of the occupant(s) with respect to the tenability conditions, however the variations of the conditions along the travel paths are generally implied rather than explicitly considered.

In considering the escape from any compartment or space it is necessary that untenable conditions do not exist at that point and time that the last occupant leaves that space. It is necessary therefore to determine -

- * the point in time at which the last occupants evacuate the relevant compartments en route to a safe place; and
- * the environment conditions at the critical locations at the relevant points in time.

This is a complex dynamic situation because throughout the fire scenario, fire and smoke are developing in all dimensions through the building, and the occupants are also moving in other (or the same) parts of the building. The conditions presented by the fire and the passage of occupants involve assessment of these with respect to time and each other.

9.2 Acceptable Solution Conditions

The Acceptable Solutions occupancy conditions presume a certain fire load (combustible content) and prescribe a specific maximum travel distance. This process implies that -

- * occupants will receive adequate warning; and
- * the fire will not grow in size to produce untenable conditions within the time required to move through the open path.

Experience has shown that notwithstanding providing sufficient Dead End Open Path and Total Open Path distances as required by the Acceptable Solutions occupants escaping from

Intermediate floors may be subject to untenable conditions (see 7.10), and if there is any doubt a designer should undertake a rational analysis.

The Acceptable Solutions do not provide any specific measures with respect to the time between the commencement of fire and the time at which occupants commence to escape. Therefore it must be inferred that the Acceptable Solutions provide an integrated approach to the escape of occupants, and any variation from the Acceptable Solutions requires the specific design of the entire process. This must include assessment of the physical conditions of the firecell and escape routes as well as the fire itself, any installed detection or fire suppression systems and the response of the occupants.

9.3 Real Conditions

When it comes to design outside the Acceptable Solutions it is necessary to also consider the fire scenario. This will require assessment of the fire, its source and growth and development and the spread of effects of heat and smoke products (see also Chapter 6). The typical approach of the Acceptable Solutions only considers firecell boundaries and not the walls and ceilings of compartments and the ventilation of the individual space. Most walls around a space will have some capability to at least hinder the spread of flame and smoke beyond that space. The likelihood of ventilation being changed by breaking glass etc, means that modeling of a real fire needs careful assessment and trials to check the sensitivity of the modeled conditions.

Refuge Areas

The provision of refuge or temporary holding areas may be important in optimising the time for safe escape. Commonly used in stairwells, refuge areas provide a space for disabled or slower moving occupants to be outside the flow, allowing others to escape. Provided the stairwell can maintain tenable conditions for an extended period, these occupants can be brought to safety by the Fire Service, or possibly make their own slower egress, without effecting the majority of evacuees.

It is important that the noise level of alarm sounders is not excessive in stairwells or places of refuge where people may have to wait for some time.

Stairwells and Smoke

Occasionally in taller buildings the stairwell will be pressurised to ensure the tenability of the shaft. Pressurisation designs generally provide an over-pressure in the shaft that will prevent the flow of smoke from a firecell into the shaft. Alternatively provision of a suitable lobby between the firecell and the stair shaft (by way of a protected or safe path) will minimise the spread of smoke into the stairwell during escape from the firecell, and maintain the tenability and integrity of the shaft. Where a stairwell is designed as providing a Means of Escape and needs to be a Safe Path (ie safe separation from the firecell) it is important to ensure the integrity of the shaft is not invalidated by doors between the shaft and the firecell being wedged or held open. Building owners and occupants need to be attentive to this item in the regular building warrant of fitness inspections. Provision of magnetic hold-opens to doors to minimise the potential for such wedging is encouraged by the writer.

Surface Finishes

The Acceptable Solutions include requirements for surface finishes in many compartments, particularly corridors and stairs etc, whether part of the exitway or the open path. Computer modeling does not allow for simulation or estimation in quantitative terms of the effect of

combustible linings on the fire growth and spread. The Acceptable Solutions conditions must therefore be accepted as reasonable until, and unless, it can be shown that the risk of fire and the hazard presented by the potential spread of flame and development of smoke will not effect the safety of the occupants.

Signage

The Acceptable Solutions require that signs be located at all Fire Exit doors except over the main entrance. A minimum size is specified, and except where emergency lighting is required illumination is seldom necessary (although a degree of reflectiveness is specified). Ideally, once the Dead End Open Path has been left, occupants should always be within sight of Exit signs for each of the escape routes available. If there is any confusion on the direction of travel to be taken beyond the sign there should also be a directional arrow. For general clarity signs are normally mounted above doorways. Unfortunately in the event of smoke accumulation that is the first area to become obscured. The use of floor strip lighting as in planes and picture theatres may be appropriate as an alternative to exit signs. Building occupants however do have to be aware of the installed systems, or else there may be confusion and failure to evacuate as would otherwise be expected.

Emergency Lighting

The Acceptable Solutions specify occupancy conditions requiring emergency lighting. Exclusion from requiring this facility is generally only permitted by the Acceptable Solutions in buildings with low occupancy numbers (and presumably therefore being smaller buildings with shorter travel paths), or in buildings which are most likely to be occupied during daylight hours. Where specific design for Means of Escape is involved (unless specific design can show that this feature is not required) then emergency lighting should be installed. Where internal egress (without any external windows) is provided, emergency lighting is recommended even if not required for code compliance. Similarly, occupancies which require egress through routes which are unfamiliar should also have emergency lighting. In both these instances escape will be much slower if visibility is poor, and this must be considered in any calculation for escape times. Emergency lighting at or near to floor level is considered by the writer to be a preferable to ceiling level lighting in most instances, because smoke across the ceiling will reduce the effectiveness of the lighting.

Design Integrity

It has been raised with the writer in discussions with a Territorial Authority that it is dangerous to rely on the integrity of a design which is in turn dependent upon the proper control of passive safety systems (such as fire and smoke control doors). This is because it has been shown that it is not uncommon for such doors to be jammed or held open during normal occupancy conditions. While it must be acknowledged that any design may be compromised by non-compliance, a properly designed, detailed, specified and managed system should minimise that likelihood. One method to avoid the jamming of doors is through the use of magnetic hold-open devices which will release upon activation of the alarm system.

This will probably require the designer to provide an operations manual for the fire safety systems which will need to be consulted in conjunction with the regular Warrants of Fitness Inspections and Evacuation Drills. Where there is an expectation that fire and smoke control doors may be jammed open during normal use consideration is recommended for use of magnetic hold-open devices which will release the doors in the event of alarm activation.

9.4 Summary

- * Correct assessment of the time of smouldering, ignition and growth phases until detection is often critical for the design for safe escape.
- * Escape is concerned with ensuring those who may be affected by the effects of fire can be evacuated, to a place of safety, before the conditions become untenable/fatal.
- * Design for escape is a dynamic problem in four dimensions (three spatial, plus time).
- * Physical limitations for smoke spread into travel paths, by fire and smoke control doors may assist in maintaining tenability conditions.
- * Refuge areas may allow the majority to escape while providing safety to those not so able to move.
- * Continued integrity of design concepts may be assisted by provision to a building owner/manager of an operational manual covering the relevant design aspects.

Chapter 10. Factors Effecting Escape Times

10.1 Introduction

This chapter discusses the critical time aspect for escape from fire and provides a basis for the assessment of times of movement.

10.2 Requirements for Evacuation

The designer for Means of Escape must consider the question -

Q. What is critical about the time required to escape from fire?

The response to this is -

A. It is the time to be safely separated from the effects of fire (ie not necessarily to the final safe place)

In general terms this is the time to gain access to a protected path, safe path or safe shaft. If the safety of that path or shaft is compromised before occupants can manage to leave this area then the critical time needs to allow for this condition.

Clearly occupants separated from the fire in a separate firecell are in a less critical situation than those close to the fire, say in the same compartment. Those occupants in an adjacent compartment to that containing the fire, but whose egress could be compromised by the fire effecting a common travel path, appear to be at risk. Particularly if there are no detection devices or occupants in the fire compartment. In this situation a fire could become well developed before occupants become aware of the danger.

Escape from the effects of fire is a time dependent exercise. The procedure to be followed requires the designer to determine:-

- * the point in time at which the fire cue will be recognised;
- * the time taken to validate the cue;
- * the time for response (pack-up, turn off computers etc); and
- * the movement times through spaces until safe.

S. North (1997/98 President of I StrE) in an unpublished address in Wellington (August 1998) indicated that escape times in excess of 8 minutes were likely to cause concern because of the delays to those involved.

10.3 Specific Results

The Approved Document C2/AS1 has been shown by Wade (1992) to imply 157 seconds (2.62 mins) as the flow time at 1.3 persons per second per metre of effective width in horizontal means of escape; and a flow time of 188 seconds (3.12 mins) for the steepest common stair permitted by Approved Document D1.

Buchanan (1994) implies that the assumed time for travel in Dead End and Total Open Paths are 1.0 and 2.5 minutes (60 and 150 seconds) respectively. Barnett and Simpson (1995) tabled escape times for seven different design alarm conditions. The escape times are

compared with tenability time limits (t_{tl}) for each of the conditions (3.0 - 13 mins). The assumptions figures summed-

t_d	time for detection
t_a	time to activate the alarm
t_t	time to validate the alarm,
t_r	response time before moving out,
t_m	time of movement

to give t_{el} , total elapsed time (6.6 - 9.6 mins) for the last person to evacuate the fire cell. It was shown that a factor of safety (t_{el}/t_{tl}) of greater than 1.0 was only achieved with sprinkler installations.

The time for detection will depend upon the fire and the location and type of detector. For a burning fire the computer models will provide times for activation of the automatic detectors, and the operation of alarms etc.

Where there is no automatic detector system, and a fire and occupants are in the same firecell, (but separate compartments) it will be necessary to consider the growth of the fire and the type of cue that will be noticed in order to assess the time to detection. (eg. Will the fire grow to the point of breaking windows or will smoke spread provide the cue?)

Most automatic detection systems will have virtually instantaneous activation of the alarms. Manual call points however may require the finder of the fire to reach the exit before activation of the alarm, or provide an oral warning to others in the firecell. The elapsed time from discovery to alarm activation may be assessed using normal travel speeds for the distances involved.

Validation of the fire cue (automatic alarm, oral warning or direct cue, eg smoke) has been noted (see Section 8.3) as a natural reaction. The time for this response will depend upon the type of cue, the specific firecell conditions and personal factors (awake/sleep, able/disabled etc). It may range from 15 seconds upwards to several minutes.

The response time to an alarm will depend upon the credibility of the alarm, the individual circumstances, and the personal actions considered necessary before moving towards an exit. Actions may include getting dressed, getting a jacket, turning off computers etc. A minimal time will probably be of the order of 15 seconds, but could range up to minutes.

Assessment of movement times is discussed in more detail in Section 10.4.

Compliance therefore with the 1.0 and 2.5 minutes of travel time (for Dead End Open Path and Total Open Path respectively) may not be sufficient to ensure the safety of occupants. This is in conflict with the implications of the Acceptable Solutions. Designers must therefore use movement times with caution as a basis for compliance with the Building Code.

10.4 Movement Times

Calculation of movement times requires the following steps -

1. determination of activities/occupancy use of the various spaces in a building;
2. determination of the number and distribution and number of occupants in any particular space at the time(s) the relevant cue is received;
3. assessment of the abilities of the individual(s) involved (are there any occupants with disabilities);
4. determination of the length of the various travel paths;
5. assessment of the physical conditions of the travel path(s);

6. determination of the number of occupants in any particular space at the relative point in time and effects of the numbers of occupants in a space upon travel movement; and
7. calculation of travel times

These travel times then need to be compared with

- * the source of fire and fire growth conditions; and
- * the tenability conditions at critical egress locations and times.

10.4.1 Step 1. Activities/Occupancy Use

The size and use of a space often defines the number of occupants likely to use the space and the fire load. The Acceptable Solutions provides tables relating to these characteristics. Experience has shown that some values may be conservative because of the range of activities/use encompassed by a particular definition. For example retail activities may have goods stacked onto high rack systems with narrow aisles or use significant floor areas for display of items with some low racks and wide aisles. The occupancy numbers derived from the Acceptable Solutions are based upon the gross floor area; whereas an assessment based upon the aisle widths, checkout queues etc could result in significantly different numbers. Similarly the fire load of the displayed goods will vary depending upon the type and display/stacking systems.

It is necessary, of course to consider the potential for changes should the tenancy/occupancy use change.

10.4.2 Step 2. Initial Number and Distribution of Occupants

It is usual to consider occupants, at the time the alarm/cue is received, as being evenly distributed throughout the relevant areas, with at least one person at the most remote location on any escape path. Where occupancy is time or event related consideration must be given to the distribution which will give the distribution which is likely to provide the most serious condition. Recognition must be given also to the reasonable possibility of distributions not considered by the owner, but which could be expected. For example school halls may be used with moveable seating as a sports area, as a dance floor or with standing crowds.

The assessment of the total occupancy numbers may be established using the appropriate values given in the Acceptable Solutions. These appear to be reasonable for some occupancy classes, eg classrooms, and individual offices. Numbers estimated for some other uses appear to be conservative. Observations have been made of a NZ supermarket operation and a survey of office buildings undertaken as part of this study (see also Section 4.3 and Appendices A and B).

Once the alarm is acted on the evacuation process is assumed to commence. This will involve occupants moving along designated routes towards safety. The potential 'catchment area' for each route requires to be recognised and the numbers likely to move along each path estimated.

Even for single level occupancies if there are several groups of persons merging into the travel paths manual calculations may become complicated. Where escape involves merging into stairs at various levels again manual calculations become complex. There are a number of computer programs which use hydraulic theories to deal with the "pressures of merging streams" to determine the times for escape. Such programs are EVACNET+ and SIMULEX; these are discussed in more detail in Section 11.6. One common factor with computer

analyses is that they appear to assume that evacuation of all occupants commences at the same time. Where the cue is given by an automatic alarm device this will be reasonable as at least those who gave the alarm will have already commenced evacuation. Allowance for initial delays, and their effects will be discussed later. It is also assumed that all occupants will proceed to evacuate, rather than be involved in fire fighting or rescue operations.

The Acceptable Solutions assume that all the occupants from a floor can freely move into a stairwell and escape without hindrance from occupants from other floors. Where the occupant load from a floor cannot enter a stairwell before the occupants from the upper level reach the merging point then queuing will occur of the lower floor occupants. (It is generally assumed that those from above will take precedence over those entering at a lower level.) If a stairway is so restrictive in width that the flow on the stairway is less than the potential flow into the stairway queuing will occur within the stairwell. The increase in density in the stairwell will further decrease the flow.

10.4.3 Step 3. Abilities of the Occupants

Pauls (1995) notes Canadian research which indicates that about 3% of occupants in multistorey buildings cannot participate in general evacuation because of invisible phobias as well as visible disabilities (eg circulatory system disorders). These occupants, however may be able to proceed after the general evacuation. Less than 1% of generally active building occupants (outside institutions etc) use movement aids, but even some of them can negotiate stairs, albeit at a slower rate. The Acceptable Solutions provides for refuge areas in stairwells in multistorey buildings and hospitals. It is recommended that similar provisions are made in other premises, particularly where queuing and/or full occupancy of the stairs is likely.

Occupancy by evacuees with movement difficulties needs to be recognised for both vertical and horizontal travel. It is to be noted that in some occupancies (eg rest homes) occupants may need assistance to get up and/or move. The design for escape in these situations must recognise -

- * the time at which warning/alarm is given;
- * the location, and activity of the occupant at that time;
- * the potential disability;
- * the availability of a staff member/assistant; and
- * the travel path -

in the assessment of the movement of the occupant to safety, each with respect to time..

10.4.4 Step 4. Lengths and Widths of the Various Travel Paths

Doors to be used for emergency (fire) egress must be designated, and the travel paths from the furthest point for each door determined. While most plans do not show the location of furniture or fittings these may significantly effect the actual route and travel lengths. Increases in excess of 25% could result, particularly with aisles similar. The widths of the escape routes, particularly at points of constriction, also need to be determined. From the distribution of the occupants it is possible to determine the 'ideal' allocation of occupants to travel paths. Wood (1972) and Bryan (1977) and with Milke (1981) found that in many instances occupants -

- * traveled towards the fire;
- * did not use the shortest distance; and
- * did not always use the route of entry to their location.

Clear indication of the escape routes, and regular training of regular occupants, will be the only way there can be confidence in the use of the designated routes and the appropriate distribution of evacuees.

The Acceptable Solutions requires handrails on both sides of stairways (for disabled access), and at no further apart than 1500mm. Reference to Tutt and Adler (1981) indicates that for two persons to travel in the same direction 1150mm between walls is required for horizontal travel. The minimum width of 700mm is given in the Acceptable Solutions for <50 persons for horizontal travel. Tutt and Adler (1981.) indicates a minimum width of 600mm (without having to turn sideways, which will reduce travel speeds). An additional 150mm is required by the Acceptable Solutions for travel on stairs, presumably because of the additional lateral motion involved. For two persons to move together on a stairway the minimum width should therefore be increased by this 150mm also. The writer considers this will therefore result in minima for design flows of:

		Single travel	Double travel
Horizontal travel	-	600mm between walls	1150mm between walls
Vertical travel	-	750mm between walls	1300mm between walls

The use of these dimensions will also require that the stair handrails do not protrude into the travel path by more than the wall boundary layer effect (see Section 10.4.7). A reduction of over 10% in travel speeds may need to be applied where conditions are outside the general limits.

For escape using ladders, aisles between rows of seats, bridges and external stairs will need specific attention to the travel velocities and the conditions during the time of escape

Consideration must be given to the likely effect of a fire on the escape routes. A blocked route may require combining the 'load' from one route into another.

Dead-end paths need to be identified as these, in particular, may be critical to escape as there is no other alternative route.

10.4.5 Step 5. Physical Conditions of the Travel Path(s)

There are a number of physical attributes other than the width and length that may effect the safe escape of occupants. Doors along an exitway must not be locked. Care will be required to ensure compatibility of security and fire safety measures.

The demands for security have resulted in installation of locked doors both external and internal (particularly in stairwells) in buildings. In some instances these are operated by keys and in others by electronic means (swipe card or combination key pad).

Doors and Windows

External doors designated for egress must be available for use by evacuees. Locking that requires use of keys or cards is not to be encouraged because of the high probability that the requisite opener is either not held by the evacuee(s) or has been left behind. Electronic controlled doors can be set to unlock upon alarm activation or an interruption of the internal power system. Security must take second place to safety in this respect.

Windows may be used for egress, but with several limitations. Unless shown as satisfactory by design, the conditions of the Acceptable Solutions should be used. Escape through windows will not be as quick as through a doorway.

Internal glazing, which may be separating the escape route from the fire compartment, are restricted by the Acceptable Solutions. Provided the glazing remains intact and the occupants can travel past without being subject to excessive radiation then safe conditions prevail. It will be necessary to show that at the relevant time the-

- * compartment temperature will not result in broken glazing ($<500^{\circ}\text{C}$ approx); and
- * radiation is $<2.5\text{kW/m}^2$.

Higher level windows, so that occupants do not have to bend down will only need the glazing to remain intact.

The Acceptable Solutions only permits doors that do not swing in the direction of travel where the numbers of occupants are limited, and they are not in the exitway itself. As doorways are generally points of restriction their width is most significant. The effect of the direction of opening of the doors requires consideration. Where the occupant density is high, opening a door back into the flow is clearly impracticable. Sliding doors (manual) are not so critical unless there is sufficient pressure from the evacuees onto the door to inhibit the opening action. Vertical sliding doors (in the writer's opinion) are possibly even more difficult to open than horizontal doors under crowd pressures. The restrictions provided by the Acceptable Solutions are therefore considered appropriate, unless or until research shows otherwise. Sliding doors on the escape route that are automatically controlled by the alarm system are permitted by the Acceptable Solutions, and do not present a problem for escape.

Escape routes at intermediate floors or balconies open to interior spaces and/or atria may be effected by smoke, particularly from rapid growing fires.

Stairwells & Handrails

The Acceptable Solutions also sets conditions for the length of vertical travel, merging of those traveling in opposite directions on stairs, egress from basements and length of horizontal protected and safe paths. The relevant conditions likely to be experienced in the stairways will need to be considered with respect to time during escape to ensure tenable conditions. If conditions are shown to be unsafe, additional precautions may need to be taken.

The Acceptable Solutions sets out requirements for handrails so that occupants may -

- * receive support, and to minimise slipping on stairs or ramps; and
- * not be subject to lateral pressures under crowd conditions.

The spacing and height of these handrails are set for an average adult. Where occupants may not conform to the height and reach of the average adult variation of the handrail conditions may be justified, but in general compliance with the handrail requirements is considered appropriate.

Chapter 11 provides guidance on the effects of stair slopes. Travel speeds may be reduced where handrail conditions are not in compliance with the Acceptable Solutions.

Carparks

Some specific conditions are provided in the Acceptable Solutions with respect to separating carparking spaces from safe paths. Unless design shows that there will be no danger these conditions should be followed.

Signs and Lighting

Similarly the Acceptable Solutions sets out requirements for emergency lighting and signage. Except at main entry doors into a building or the sole door into an office (or other room) occupants should always be able to see signs to the fire exit (or only one sign for a single means of escape).

Escape routes must be clearly identified, provide clear passage, and be illuminated for maximum efficiency. The regular Warrant of Fitness inspections may assist in ensuring that the first two of these conditions are maintained. Because emergency lighting provides generally a low level of illumination, travel velocities may be reduced under this condition. A guess of this is possibly a 10% reduction. If there are external windows ambient lighting may assist escape during daylight hours. Escape at night, under blackout and possibly smoke conditions will be impracticable as a design condition.

The requirements for illumination/reflective surfaces, size of signs and specific location could be a subject for a separate study. Pending such work compliance with the Acceptable Solutions is recommended.

While occupants may move through smoke, and the extent of movement may be enhanced with improved lighting the design for illumination in smoke conditions requires further study. The provision of emergency lighting in excess of the requirements for compliance with the Acceptable Solutions is recommended.

Wood (1972), Bryan (1977) and Canter (1990a) showed that over 50% of occupants do move through smoke. It has been noted in Section 7.3 that provided the upper layer does not extend below the head height before evacuation, then escape will generally be safe.

There may be some instances where some smoke can not be avoided, possibly in single means of escape in stairwells. Recommendations on visibility limits in smoke are provided above (see Chapter 7). Calculation of the volume and/or density of the smoke may be necessary if movement through smoke appears necessary, but should be used with caution.

10.4.6 Step 6. The Location of Occupants With Time

From the time at which evacuation commences the distribution of evacuees is relevant to the extent of the time at which the last person leaves each section of the route. The conditions at these times are then reviewed. If the fire and combustion products are only affecting one compartment or area, the times/conditions at each of the exits is probably all that is required. With a more complex structure layout and exits other scenarios may need to be considered. The time at which a fire occurs may be particularly important where occupancy conditions and capabilities vary during any 24 hour period.

The number of occupants in each area may vary with time depending upon the usage of the building. It may therefore be necessary to consider a range of situations to determine that which is most critical. It is implicit in the Building Act that the most serious likely condition must be applied.

It may however be possible in design terms to balance the permanently installed safety systems together with management staff controls against the various risks. For example, the option of providing additional staff during the 'graveyard' shift at a nursing home for assistance of occupants to escape may be balanced against the installation of sprinklers and smoke detectors. It is implied from the BIA (1997) publication that the Building Industry Authority is not generally in favour in reliance upon management processes as a technique for achieving fire safety.

10.4.7 Step 7. Calculation of Travel Times

The rate of flow of evacuees will depend upon estimation of the density of the area involved. For the initial evacuating firecell, this density can be from the number of occupants of that space. The time for the first and last person to reach the exit door can be calculated, and the time for all the occupants to egress from that space determined, assuming that there is sufficient space in the next area for all the occupants. Wade (1992) provides a means of calculating the speed of evacuees along horizontal paths and down stairs. These calculations are based upon data from Pauls (1995).

Manual calculations permit the assessment of travel times with respect to the times at which occupants receive the cue and the appropriate delays for those persons. Computer simulations do not appear to have this capacity. It is therefore necessary to assume, in general, that all occupants commence to move with the person with the slowest response.

The travel time for escape is seldom the time for the most remote occupant to move uninhibited through the doors, corridors and stairs etc of the escape route leading to a safe place. Even a small number of occupants may crowd a space and result in delays. This is particularly likely in multi-level buildings where those moving from a higher level generally assume precedence over those trying to enter a stairway. Consideration of travel and merging flows (including stairwells) is illustrated in Figure 10.1. Equations for flow rates for horizontal and vertical travel are given in Chapter 11.

10.5 Alternative Routes

The provision of alternative routes may not be sufficient to ensure safety. The general assumption is that travel will be in a direction away from the fire, and so must be safe. The designer must confirm however that the occupants will be able to escape by whatever route from the effects of fire.

10.6 Summary

- * Safe escape from fire requires separation from the fire.
- * Compliance with the times.
- * The time between commencement of the fire and reaching safety can be divided into segments for each phase of occupant response and/or action.
- * The abilities of occupants and the conditions existing on the escape routes require assessment for every situation.
- * Less than “ideal” conditions will result in reduced travel speeds.

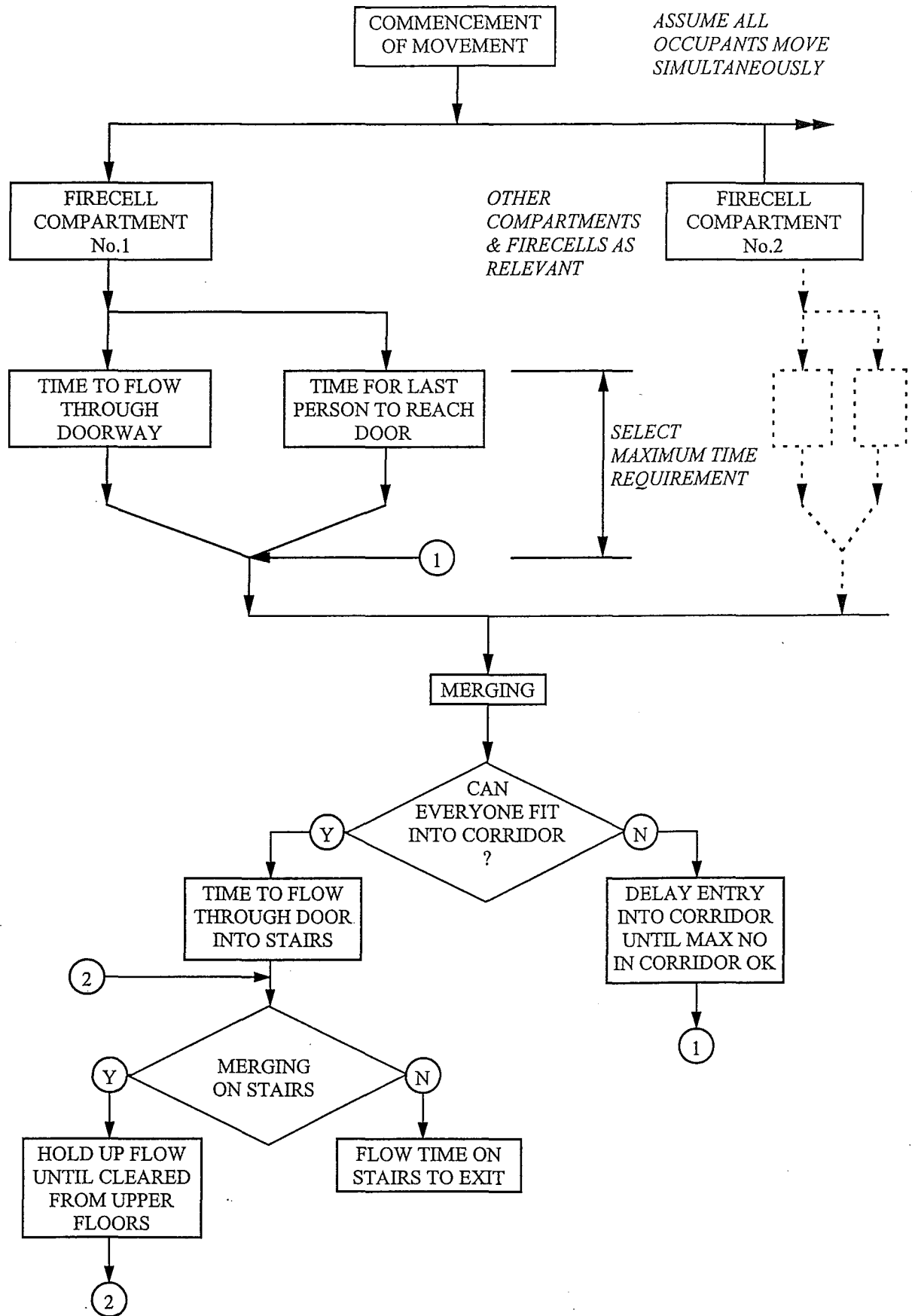


Figure 10.1.1 Escape Flow Process Example for Merging & Stairs

Chapter 11. Calculation of Travel Times

11.1 Introduction

This chapter expands on Step 7 (10.4.7), giving equations for calculation of speeds for horizontal and vertical travel including merging flows. Allowance may also be necessary for other factors as discussed in Chapter 10.

11.2 Horizontal Travel

Buchanan(1994)/Pauls(1995) provides an equation for travel velocity on horizontal routes

$$\begin{aligned} S &= k_t*(1-0.266D_o) \quad \text{m/min} \\ &= 84*(1-0.266D_o) \quad \text{m/min} \end{aligned} \quad \text{eq 11.1}$$

where D_o is the occupant density (but not less than 0.5p/m^2),
and giving a maximum of 72.8m/min (1.21m/sec).

This value of S can be used to determine the specific flow, F_s from

$$F_s = S*D_o \quad (\text{people/min/metre}) \quad \text{eq 11.2}$$

Pauls (1995) has shown that specific flow peaks at about 1.8 persons/sq.m , with max F_s (F_{sm}) m/min also dependent upon the slope of the element route, as shown in Figure 11.1 Buchanan (1994) with modifications from Pauls (ibid) and Wade (1992) and Table 11.1 gives:-

Table 11.1

Exit Route Element		F_{sm} (m/min/m (effective width))
corridor, aisle, ramp		78
stairs (mm)		
riser	tread	
191	250	56.4
178	280	60.6
165	305	65.4
165	330	69.6

Occupancy densities for areas should not exceed 3.8 persons/sq.m as movement from such a crowded condition through any restriction (eg a doorway) may result in an arching effect to the extent that movement is completely choked (ie zero flow).

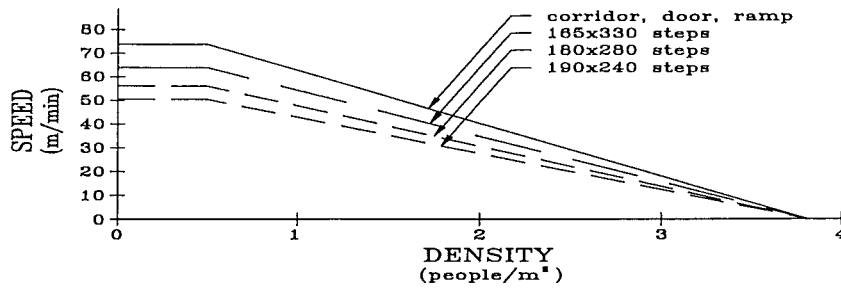


Figure 11.1 Evacuation Speeds for egress calculations

The times to traverse the shortest and longest paths in the relevant compartment area can be determined. For a uniform distribution of occupants in the compartment the nearest person may be assumed as being at the exit.

The effect of the transition from an open route through a doorway can be calculated using -

$$W_e = W - B \quad \text{eq 11.3}$$

where: W = the width of the doorway (m)
 B = boundary layer width = 0.15 m each side
= 0.3 m for two sides

The calculated flow through the doorway becomes-

$$F_c = F_s * W_e \text{ (people/min)} \quad \text{eq 11.4}$$

But where a significant number of occupants are elderly, very young or unfamiliar with the exitway the resultant flow will be reduced by 20%-

$$\text{ie } F_c' = 0.8 * F_s * W_e \text{ (people/min)} \quad \text{eq 11.4a}$$

and the time for free evacuation of the N occupants of the compartment is-

$$t_r = N / F_c \text{ (min)} \quad \text{eq 11.5}$$

11.3 Vertical travel

For stairways, the effective width W_e may be calculated from the lesser of-

$$W_e = W - B$$

where: W = the width of the doorway (m)
 B = boundary layer width = 0.15 m each side
(= 0.3 m for two sides); and
 B = 0.09 m from the centreline of each
handrail (= 0.18 m for two sides).

This may then be used to calculate P_e (mm) effective width/person as

$$P_e = 1000 * W_e / N \quad \text{eq 11.6}$$

(provided P_e is not < 28mm/person)

Wade (1992) also allows for the variation in the ratio of stair treads to risers, ascending travel and persons who are elderly, very young or unfamiliar users as follows:-

for treads, dimension T (mm) >280 ;	e_t	=	$280-T/500$ (max -0.1)	eq 11.7
T (mm) <280 ;	e_t	=	$T-280/500$	eq 11.8
for risers, dimension R (mm) <180	e_r	=	$180-R/500$ (max -0.05)	eq 11.9
R (mm) >180	e_r	=	$R-180/500$	eq 11.10
for ascending stairs-	e_a	=	-0.1	eq 11.11
for elderly, young, unfamiliar -	e_d	=	-0.2	eq 11.12
These factors are combined as -	e_f	=	$(e_t + e_r + e_a + e_d)$	eq 11.13

The time for people to escape on these vertical escape routes may then calculated from-

$$P_e = 8040 * N * e_f / (t^{1.37}) \quad \text{eq 11.14}$$

where t is in seconds. This equation can be rearranged to give

$$1.37 * \ln(t) = \ln(8040 * e_f / P_e) = \ln(T') \quad \text{eq 11.15}$$

$$\text{ie } \ln(t) = \ln(T') / 1.37 = T'' \quad \text{eq 11.16}$$

$$\text{or } t = e^{T''} \quad (\text{secs}) \quad \text{eq 11.17}$$

It should be noted that various sources use the term goings and others use the term treads. These are not normally the same, as in it is more usual to provide a nosing to a stair tread so that it overlaps the tread below so that-

$$\text{tread} = \text{going} + \text{nosing}$$

This nosing may be 20 - 25mm. This variation in value will generally make very little difference to the calculated times however.

These calculations therefore result in the time for escape for a number of persons to pass a particular point on a stairway. It does not provide the actual travel time from floor to floor or the speed of travel (m/min).

For low densities (again using D_s not $< 0.5p/m^2$) the stair slope is calculated as -

$$\begin{aligned} \theta &= \tan^{-1}(\text{Riser/Going}); \text{ and with} \\ \text{interstorey height} &= h \text{ (m)} \\ \text{stair slope length} &= L_s = 1 + h/(\sin(\theta)) \text{ (m)} \quad \text{eq 11.18} \end{aligned}$$

(allowing 1m for landing length)

$$\text{For stairs} \quad k_t = 51.8(G/R)^{0.5} \quad \text{eq 11.19}$$

Using the minima of the actual flow of people as they approach the stair, and the width of the space (stairs) $(F_c/W_e \text{ p/min/m}) = F_s$.

$$\text{Now, relating } S = k_t * (1 - 0.266 * D_s); \text{ and } - F_s = S * D_s \quad \text{eq 11.20}$$

$$\text{So using } F_s = k_t * (1 - 0.266 * D_s) * D_s; \quad \text{eq 11.21}$$

we have a quadratic equation for D_s where -

$$\begin{aligned} a &= 0.266 * k_t \\ b &= -k_t \\ c &= F_s \\ (\text{as } D_s &= (-b \pm \sqrt{b^2 - 4ac}) / 2a) \end{aligned}$$

Selecting D_s closest to D_o above-

$$S = k_t * (1 - 0.266 * D_s) \text{ m/min} \quad \text{eq 11.22}$$

Allowing for a landing length (L_a) we can then calculate the travel time as-

$$t_r = (L_s + L_a) / S \text{ min} \quad \text{eq 11.23}$$

Commonly this time is around 0.15 minutes for floor to floor travel.

11.4 Merging Paths

Once several spaces feed into a common area (eg into a corridor or lobby) then a higher density may result. The flow of people from this 'common' area will be a function of the density, within the limits values noted above.

This new density should then be calculated, and the time for egress from that area be calculated.

As occupants can be assumed to be leaving while others are arriving the specific flow F_s can be calculated (Nelson & MacLennan, 1995) from -

$$F_{s(out)} = F_{s(in)} * W_{e(in)} / W_{e(out)} \quad \text{eq 11.24}$$

where (in) refers to entering the transition point; and
 (out) refers to leaving the transition point.

For situations with two incoming flows and one outflow from a transition point, as may occur with a flow down a stair merging with a flow entering the stair, then the calculated flow -

$$F_{c(out)} = \{ [F_{c(in1)} * W_{e(in1)}] + [F_{c(in2)} * W_{e(in2)}] \} / W_{e(out)} \quad \text{eq 11.25}$$

where $(in1)$ and $(in2)$ refer to the relevant two inflows.

(A similar equation can be used for variations on the above conditions)

Where the calculated specific flow from equations 11.24 or 11.25 leaving a transition point exceed F_{sm} a queue will form on the incoming side of that point. The queue will grow at the incoming rate minus the calculated flow leaving the point.

Where the calculated outgoing flow is less than the F_{sm} for that section of the route there is no way to predetermine how the routes will merge. It will be conservative to assume that the route of interest (ie escaping from the fire compartment) is dominated by the other route(s).

A worked example is included in Appendix C, for merging flows into a single stairway.

11.5 Tall Buildings

Pauls (1995) has noted experimental results times for escape from taller buildings. He also provides that the time taken from start of movement to mean flow condition takes 41 seconds. He has built this into equations for total evacuation times T_t (min), from

$$P = N / W_e \text{ persons/m} \quad \text{eq 11.26}$$
$$\text{where } P < 800, t_{ev} = 0.68 + 0.081 * P^{0.73}; \text{ or} \quad \text{eq 11.27}$$
$$\text{for } P > 800 t_{ev} = 0.70 + 0.133 * P \quad \text{eq 11.28}$$

These times are based upon time from alarm, and a confidence in the reliability of the system. Nelson and MacLennan (1995) noted gross variations in times because of the variations in the times in receiving and the acceptability of the cues received.

11.6 Computer Simulations

The EVACNET+ computer program by Kisko, Francis and Noble (1984) provides an interactive program that models evacuations of buildings. The program identifies an optimal

plan to evacuate the defined building (see below) in the minimum amount of time using an advanced trans-shipment algorithm

In EVACNET+ the user must define the nodes (building spaces/elements) and their arc relationship for travel routes. The program operates in time interval units as defined by the user. There is a maximum number of 60 time intervals. The user may however define each interval to whatever is an appropriate time span - eg 5 secs.

For each interior or source node the capacity (total occupancy based upon the potential queuing density) and initial occupancy number must be entered. Destination nodes may have upper and/or lower bounds of occupancy defined or default values of 32766 and zero respectively will be assigned.

Arcs are defined in the direction of travel, and thus where options of direction are possible each must be modeled separately. For each arc the dynamic capacity and traversal time is required. The EVACNET+ Users Manual provides a guide for dynamic capacity based upon levels of service, and average speeds of travel. This will allow computation of the traversal time in minutes. From this and the width of the travel element, the average flow volume can be calculated in persons/minute. From these the dynamic capacity (persons/time interval, and the traversal time (number of time units).

It appears necessary to use integer increments in entering the program which may require some approximations that could effect the result.

Other computer programs available are as noted by Holmberg (1997) include EXITT, EVACSIM, EXIT89, EXODUS and SIMULEX. SIMULEX utilises CAD plan layouts and uses an interperson distance rather than occupant density (ie as individuals rather than as a crowd) and has the advantage also of showing the evacuation live on the screen, readily showing bottlenecks and queues etc.

The computer models all appear to assume that all users receive the alarm cue and commence movement simultaneously. The relevance of this assumption upon escape times must be assessed for each situation.

Using the design data and the above procedures the time to evacuation of relevant compartments or spaces can be calculated. The times can then be compared with the tenability conditions at or immediately prior to evacuation. The safety of the situation, and any margin (if required) can then be determined.

11.7 Integration of Escape Procedures

A Process Chart (Figure 11.2) is provided to illustrate the inter-relationship between the fire and development of untenable conditions and the processes and times required for escape. As noted above (Section 9.1) fire and evacuation conditions provide a dynamic situation in four dimensions. The chart presents this in a two dimensional form. It may be necessary to consider a number of options or scenario to determine the most critical situation. Basically the processes follow the two time lines; one for the fire, its growth, production of combustion products and the conditions (tenability) at the selected location; the second time line follows (for the specific occupancy conditions) the receipt of the cue, recognition, investigation response and the escape to the selected location (leaving the fire effected area and/or entering an area of relative safety). The chart has been drawn assuming occupants are present in the firecell, but it will be necessary to confirm that they are the occupants most at risk.

11.8 Summary

- * The times for each phase in the fire growth, alarm cue and escape process must be assessed.
- * Movement times will be effected by occupancy use, numbers of occupants, distribution of occupants within a building (initially and during the escape period) and their abilities for escape movement.
- * Movement times will be affected by characteristics of the path, its width, length, slope and presence of stairs. A density of 3.8 persons/m² may result in arching/blocking across escape routes, and no movement.
- * Computer simulation models are available and are particularly useful where merging and queuing occur. All programs appear to utilise the a simultaneous start of movement time.
- * Matching of time lines for fire conditions and evacuation movement clearly identifies the extent to which the proposed Means of Escape is 'safe'.

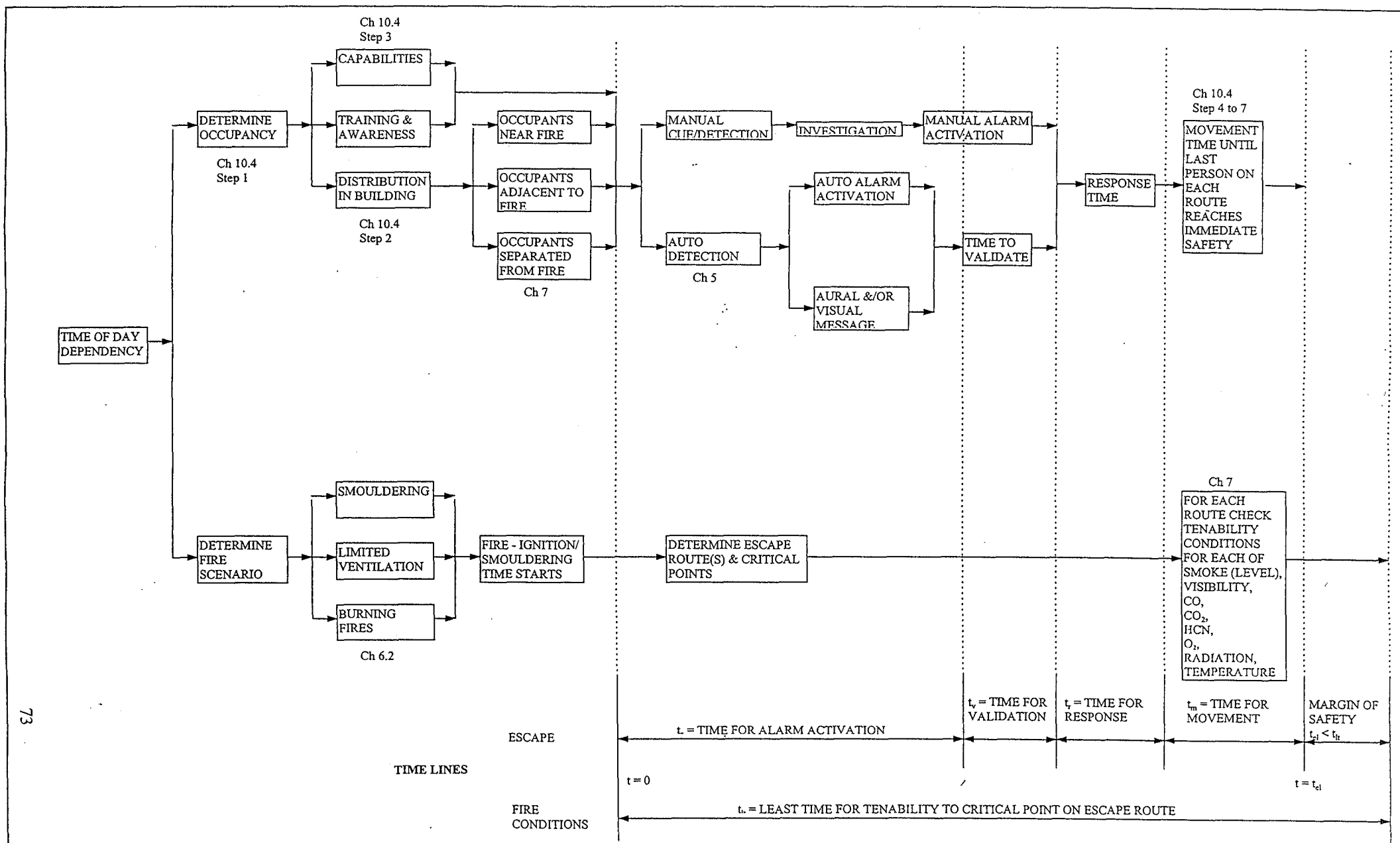


Figure 11.2 : Relative factors in times for escape tenability and safety

Chapter 12. Training

12.1 Reports on Training Effectiveness

Wood (1972) reported that where training/instructions had been provided 'raising the alarms' and 'evacuation of others' were undertaken more consistently as first responses to alarm cues. The more frequent this training (at least to monthly) the stronger this response.

Bryan (1977) noted that previous experience of a fire by occupants did not result in significantly different responses to fire cues. In his 1983 report Bryan does note that those who had experience/training tended to move further through smoke.

Haber (1990) notes that the training of staff in health care facilities to close doors and pass on warning cues were significant in saving lives. The provision of adequate staff to undertake evacuation and care of occupants was also stressed in this study.

The loss of life in the MGM Grand Hotel fire may have been reduced if there had been a fire emergency plan which would have resulted in warning to the fire department and building occupants (Best and Demers, 1982).

12.2 Training of the Public

The writer remembers a series of television advertisements dealing with fire safety fronted by Dick van Dyke in the early 1980's. These dealt with 'drop and roll', 'check the door temperature before opening' and 'crawl to avoid smoke'. These were also remembered by the writer's children who were then aged about 10 - 20 years. Repetitions of such a campaign (with additions of care with candles and other matches, closing of doors, calling for help etc), could possibly draw more attention to the problems and reduce fatalities than the occasional horror news-clip. Regular reinforcement/training however, must be provided if the message is to be remembered and acted on. New Zealand schools have long provided earthquake response training for classes. This training needs to extend to care with fire, and response to fire cues.

12.3 Management Approaches

The Building Industry Authority has previously been requested to provide Determinations on the provisions for fire safety in buildings where an applicant has requested variations from the NZ Building Industry Authority Acceptable Solutions. The Building Industry Authority clearly stated (Determination 97/007) that it is unwilling to rely upon specific management action, eg by provision of specific staff/client ratios for health care facilities, to ensure safety of occupants likely to be subject to fire. This is notwithstanding the Fire Evacuation and Safety of Buildings Regulations which requires the training of staff.

The NZ Fire Service have specified that for health care facilities not only must premises comply with the Acceptable Solutions, but also provide a specified staff/client ratio. A decrease in the ratio being permitted if additional installed protection measures (eg smoke detectors as well as sprinklers) over and above those required in the Acceptable Solutions are installed. Doubts have been raised as to the validity of these requirements at the time of writing by the building industry..

This is also notwithstanding the requirements of the Fire Safety and Evacuation of Buildings Regulations which requires the training of staff. It is the opinion of the writer that circumstances may dictate the most suitable measures to be provided, and this may be a combination of fixed systems and management (staff) measures. Such an approach may be appropriate, in particular, for one-off situations and where clear controls can be put into place. Staffing levels at, or above, the minimum acceptable for other than fire safety could all too easily be overlooked through changes in management, occupancy, etc. Twice yearly reviews by the Fire Service leaves too many opportunities for the procedures to lapse.

12.4 Regulations for Evacuation Exercises.

It has been noted (see Section 2.5) that the Fire Safety and Evacuation of Buildings Regulations in New Zealand require regular evacuation exercises. It is the opinion of the writer that six monthly is probably all that is acceptable and all that is practicable for most commercial and business enterprises.

Employers must be encouraged to not only ensure the exercises are undertaken at the prescribed intervals, but that new employees are instructed in safe work practices including the means of escape, warning/alarm locations and signal type (siren, bell, whistle etc), at the time of commencement rather than waiting for the next regular exercise. The writer notes that many businesses require visitors to register at entry into the premises, and include instructions on the means of escape; however the attention given to this latter detail/instruction is minimal, and often not recognised by the visitor.

For building occupants to receive the maximum benefit from the evacuation drills it is the opinion of the writer that -

- * drills may be advertised so that “false alarm” scenarios are eliminated; and
- * different/alternative routes (where there is more than one) should be tried.

Under these conditions occupants become aware of the alarm(s) and safety conditions and have confidence in the operation of the system.

Buildings which are occupied on an intermittent and/or transient basis (eg churches, universities, motels and hotels) must take steps to ensure that occupants are aware of the relevant signals and means of escape.

12.5 Design Implications

While Haber (1990) did attribute the training of staff in health care facilities as being responsible for the saving of lives, there is no clear qualitative measure of the effectiveness of training in improving the safety of building occupants, or the decrease in time required for the evacuation of premises that can be used in the design situation.

Basic training and fire drills can be expected to provide regular occupants of offices, workshops and education facilities with knowledge of the evacuation route(s) and so minimise the potential for panic, increase the awareness with respect to requirements of those occupants with special needs and ensure that evacuation routes are kept clear. This is seen as a positive step for improving awareness of the requirements for safety in the event of a fire requiring evacuation.

For institutions providing care it may be practicable to use data from comparable situations, if they are available, to verify the times in the final condition with suitable factors of safety

incorporated. (eg By verification of the times taken to rouse and evacuate sleeping elderly occupants.) Should actual practice not be in accordance with the design values then changes will be necessary. These may involve significant and possibly unacceptable costs and delays to a business in comparison to a design that did not rely upon training as a basic premise.

Training for evacuation of premises with irregular or intermittent occupation, such as churches, appears likely to have minimal effect in increasing the safety of occupants. It is important, therefore, to ensure that responsible leaders of such activities are aware of installed alarm systems (if any) and the safety procedures and routes necessary for evacuation (eg by personally checking of the routes, signs and doorways etc).

For cinemas, theatres, motels, hotels, shops and restaurants which have transient populations training of staff may be essential to ensure that occupants respond quickly to an alarm, and leave by the most appropriate exit. As with care institutions there appears to be no measure of the effects of training to assist in specific design. Use of data from similar situations may be appropriate, but would have to be used with caution.

12.6 Summary

- * Regular evacuation drills are considered as a useful training for means of escape.
- * Training of staff needs to be pertinent and regular.
- * Visitors to buildings need to be made aware of fire safety measures.
- * Public awareness/training through TV may be an effective way of reducing hazards/risk.
- * The Building Industry Authority is unwilling to rely upon management measures by provision of staff and staff training to ensure safety under fire conditions.
- * Training and fire drills can be expected to provide regular occupants of offices, workshops and education facilities with the confidence in the general systems.
- * Reliance upon training as a design tool to ensure specific occupant actions are undertaken for fire safety needs to be used with caution.

Chapter 13. How Safe Do We Need To Be?

13.1 “It Can’t Happen to Me”

Unfortunately most people consider that they will not be involved in a fire situation, or if they are that it will not be serious. The (ir)regular unannounced evacuation drills tend to reinforce the sense that fire alarms are false and a nuisance. Where fire drills are announced this encourages recognition as a safety exercise and ownership/interest in ensuring that the exercise is real, even if a nuisance. This however does not assist in the real expectation of a fire, or the potential danger. Three questions arise with particular respect to Means of Escape-

- * What is the probability of fire?
- * What is the probability of a fire at peak occupancy?
- * What is the acceptable risk of fire that may result in injury or death?

Bryan and Milke (1981) noted that over 49% of their survey population had previous fire experience. A comparison with the NZ probability of around 1 in 50 years would provide a similar figure to Bryan’s for fire experience for an adult group.

Custer and Meacham (1997) note that there are challenges in quantifying uncertainty in performance based fire protection.

Ramachandran, (1995) provides a discussion on values of life, injury and reduction in risk. He also discusses ethical issues and the consequences of single and multiple death fires.

13.2 Single Means of Escape

The Acceptable Solutions permits single Means of Escape -

- * that do not exceed the allowable Dead End Open Path;
- * with limits on the numbers of occupants, and in particular where there are pre-school children or disabled occupants;
- * with limitations on purpose groups;
- * with limitations on the Fire Hazard Category; and
- * with limits on building height.

The limitation on the Dead End Open Path is consistent with the general application of the Acceptable Solutions, with early warning from detectors or potential control by sprinklers being translated into a travel distance or equivalent time.

The implications of limiting the number of occupants and purpose groups appears to be to control the magnitude of the risk.

The limitation of the Fire Hazard Category is related to the FLED and, it implies, the rate of growth of the fire. The faster the rate of growth, the shorter the time until untenable conditions will be developed. This, however, is not consistent with assessment of the actual combustibles, and their individual fire growth potential.

The reasoning on limitation on building height is unclear as the travel distance will be within the Dead End Open Path or an exitway (safe path) will have been entered. It may have been assumed that smoke from a lower level could enter the safe path (from those evacuating at a

lower level). The height control would therefore limit the potential travel distance down through smoke.

A single Means of Escape requires the designer to exercise additional care in the assessment of the safety conditions. Where an alternative route is available the risk of exposure in design is halved.

The time until movement conditions may not differ whether there are one or more Means of Escape. Where there is only a single escape path, and particularly if that path involves traveling past the fire, then assessment of the exposure conditions and the location of the occupants, with respect to time, may be critical.

13.3 Assessment Model

One methodology for design in the reliability of safeguard systems has been developed (Pollard, 1998). While initially for equipment the approach appears viable for fire safety also. Standards are being developed, with IEC/SC65A Functional Safety of Safety Related Systems (an international standard that is still in draft) probably being most relevant.

A Safety Integrity Level is determined from a Risk Graph. Input into the procedure are the cause, frequency and possibility of avoidance for demand for safety, and the consequence(s) of the system not working

The approach is to select the relevant category in each of the following groups/functions, and then enter Table 13.1 (Pollard, 1998).

Consequence

- C₁ Minor injury.
- C₂ Serious permanent injury to one or more persons; death to one person.
- C₃ Death to several people.
- C₄ Very many people killed.

Frequency and Exposure Time

- F₁ Rare to more often exposure in the hazardous zone.
- F₂ Frequent to continuous.

Possibility of the Unwanted Occurrence

- P₁ Possible under certain circumstances.
- P₂ Almost impossible.

Probability of the Unwanted Occurrence

- W₁ A very slight probability that the unwanted occurrence will come to pass and only a few unwanted are likely
- W₂ A slight probability that the occurrence will come to pass and a few unwanted occurrences are likely.
- W₃ A relatively high probability that the unwanted occurrences will come to pass and frequent unwanted occurrences are likely.

Table 13.1 - Demand and Safety Function
(Pollard, 1998)

Consequence	Frequency	Possibility to Avoid		Probability of Unwanted Occurrence		
				W3	W2	W1
C ₁			>	a	0	0
C ₂	F ₁	P ₁	>	1	a	0
C ₂	F ₁	P ₂	>	1	1	a
C ₂	F ₂	P ₁	>	2	1	1
C ₂	F ₂	P ₂	>	3	2	1
C ₃	F ₁		>	3	3	2
C ₃	F ₂		>	4	3	3
C ₄			>	b	4	3

These then give -

Safety Integrity Level	Safety Related Protection Systems
b	Redesign required
4	$\geq 10^{-5}$ to 10^{-4}
3	$\geq 10^{-4}$ to 10^{-3}
2	$\geq 10^{-3}$ to 10^{-2}
1	$\geq 10^{-2}$ to 10^{-1}
a	No special requirements

The requirement of the Building Code is to safeguard people from injury or illness from fire. To meet this condition clearly several deaths are unacceptable, and minor injury may be acceptable. The intermediate consequence C₂ therefore becomes the entry point into Table 13.1.

As a building occupant is likely to be continuously exposed to a hazard while present in the building entry into Table 13.1 is at F₂.

Being in the premises implies impossibility to avoid the occurrence so enter Table 13.1 at P₂. At a slight probability an unwanted occurrence will occur, and even a few may be likely entry into Table 13.1 is made at column W₂.

The common row for C₂, F₂ and P₂ and column for W₂ require a Safety Integrity Level factor of 2. This requires that the reliability of the safety systems will need to be better than 10^{-3} (ie - less than one in one thousand).

In many instances this approach may not be practicable, however some situations may lend themselves to this procedure, particularly for single means of escape

13.4 Factors of Safety

Factors of safety are generally meaningless numbers unless the designer has clarified the areas of uncertainty, correctly applied principles of conservatism, and possibly used sensitivity studies in these steps.

The selection of a safety factor will also depend upon the derivation of the numbers being compared in the design equations. If comparison is to be made between the most likely time for escape with the most likely time to untenability, a factor of safety will be essential. Where comparison is to be made between extreme values (eg fastest possible fire growth with the slowest possible travel time) a factor of safety will be unnecessary.

Because this is not an “ideal world” extreme values for all the time elements involved in the design for safe Means of Escape are not generally applicable. It is normally necessary to consider the more likely values for at least some of the time elements, and provide a factor of safety as appropriate to the degree of uncertainty involved.

13.4.1 Uncertainty

There will be uncertainty in all aspects of design for safe Means of Escape of occupants from buildings. The designer assumes many factors in the assessment process, including -

- * the time of day;
- * the number of occupants, their distribution within the building and their capabilities (awake, able-bodied?);
- * the type of fire, its position, its rate of growth;
- * tenability limits for occupants;
- * the time for response of the detector system/alarm cue;
- * the response of the occupants to the cue (investigate?);
- * the time to ‘move out’; and
- * the escape time including queuing as appropriate.

13.4.2 Conservatism

Conservatism is a useful concept, but it must be applied to producing the more critical condition. Assuming a larger/faster fire and slower speeds of travel than anticipated will result in a potentially shorter time in tenability limits, and a longer time/increased risk of exposure to untenable conditions. However the faster fire may result in optimistic response times for the activation of sprinklers, and control of the fire (ie reducing tenability problems).

13.4.3 Sensitivity Studies

Consideration of variations in design factors may indicate the variables which have lesser relevance in respect to the safety of the occupants. In many instances it will be the rate of growth of the fire and the time for the smoke to descend to head level that will provide the most critical conditions for the time to escape.

The time occupied by investigation, which -

- * actual validation of the cue, definition of the magnitude of the risk; and
- * the preparation to move (which may include getting dressed, gathering up the family, pets or valuables and/or turning off appliances);

may exceed the actual time required for escape. A Safety Factor of at least 2 is recommended by Custer & Meacham (1997) for these actions.

None of these times are specifically incorporated into the Acceptable Solutions, and, as has been noted earlier, the time to receipt of the cue and the time to commence movement may be critical in the eventual safety of the building occupants.

Where sensitivity studies show that certain parameters do not make a significant difference then a reduced factor of safety may be applicable.

13.5 Summary

- * Survey data would indicate that approximately 50% of adults have, or will have, intimate involvement in a fire safety situation.
- * Single Means of Escape, particularly where travel past the fire source is required, are a significantly greater risk than where an alternative route is available.
- * An assessment model for reliability of systems may be pertinent in considering the safety of occupants.
- * Factors of safety require careful application if the design is to be realistic.
- * Factors of safety may be reduced where studies show results are insensitive to various parameters.
- * Extreme cases will require no margin for safety whereas most likely cases will require margins for safety.

Chapter 14 . Conclusions

The main objective of this study was to propose a design procedure for safe escape from fire.

The conditions that relate to the development of a fire and its growth, the effect of these upon tenability conditions and detection systems (manual and automatic) have been discussed. The source locations and frequency of fires, and the reactions to fire in New Zealand and overseas have been provided to illustrate some of the factors affecting safe escape from fire. It has been shown that many aspects of escape route design can be quantified, but some prescriptive rules are useful as a starting point.

The Acceptable Solutions 'design rules' have been considered and the necessity to consider the design for safe egress as complete entity, not just a variation of some section or part of these 'rules' has been noted.

The Acceptable Solutions are not always applicable, and while generally conservative, may not always meet the Building Code objectives.

The non-cooperation of a supermarket chain precluded a more comprehensive study of retail occupancies. A survey of five of the larger office buildings in Wellington indicates that the maximum density on a floor may be significantly above, and the average on the gross area appears close to the net figure, given in the Acceptable Solutions. Safe design may require consideration of the higher density that may occur in New Zealand.

Occupancy density figures for New Zealand conditions show variations from those in the Acceptable Solutions and merit further research, to ensure that reliable figures are used for design.

Steps to be followed in the design for safe egress have been presented, together with some flow charts to highlight the time line concept for both the fire and the progress towards egress.

Factors of safety have been considered, and their importance and significance to various aspects of the design process. Particular importance is placed upon the requirements for single means of escape.

The design of safe Means of Escape depends upon -

- * the accuracy of selection of the fire growth model (which also includes the nature of the combustibles and the ventilation control factors), for that prescribes:-
 - * the time at which a cue is given; and
 - * the tenability of conditions with respect to time and locationExploration of the variables will provide the designer with the opportunity to express confidence in the chosen model.
- * the conditions of the escape routes. This is a matter initially of design and of continuing management. Confidence in this factor, should be assured through controls at construction and regular inspections.
- * the assessment of the number and distribution of occupants and their capabilities within the building at the time of the fire.

- * the reliability of the detection 'system' (manual or automatic). Time variation in the 'detection' may vary between individual automatic detectors. Manual recognition of the cue is imprecise by its very nature. This item will require a margin for safety, which will be dependent upon the assessed reliability of the warning cue.
- * the time taken from receipt of the cue to commencing to move along the escape route has been shown to vary considerably. It will depend to some extent on the nature and perceived reliability of the cue. The time taken will also depend upon the actions taken with respect to-
 - * recognition of the cue;
 - * investigation;
 - * fire fighting;
 - * warning others;
 - * closing doors and windows, turning off equipment etc; and
 - * gathering of personal affects
 This phase also will require a margin for safety which will depend upon the design and assumed conditions.
- * the time taken for occupants to move beyond the immediate effects of the fire.
- * Improved public education on the correct steps to take in the event of fire:
- * Announced Fire Drills, to improve acceptability of the process and general evacuation response.

Recommendations for further study

It was found that training to respond to fire cues could significantly effect the times for evacuation. Research into the provision of specific training, and the responses to evacuation drills required under the Fire Evacuation and Safety of Buildings Regulations would also provide designers with some data which could be included into calculations.

Further study into the delay times involved in the period from receipt of fire cues and commencement of evacuation travel may be valuable in providing designers with a realistic estimate of times which can be used in practice.

It has been shown that design for safe Means of Escape to comply with the requirements of the Building Act is possible by rational processes. The resulting design will be at least as effective and efficient as that of the Acceptable Solutions.

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APPENDIX A: SUPERMARKET OBSERVATIONS

Area No	Activity	Max No Occupants	Density p/m ²
1	Fruit	65	
2	Meat	35	
3	Dairy	27	
4	Aisle M	25	
5	wines etc	23	
6	Biscuits	21	
7	Plastics	20	
8	deli/toys	40	
9	end aisle	29	
10	B'kfasts	18	
11	Cleaners	26	
12	Bread	12	
13	counters	136	0.861
14	Aisle X	24	
15	foyer	30	

APPENDIX B

OFFICE BUILDING - SURVEY OF OCCUPANCY NUMBERS

OFFICE BUILDING SURVEY

BUILDING	n	floor	No occupants	Area m ²	density p/m ²	av-diff	(a-d) ²
WTH	1	8	5	222	0.023	0.03424	0.00117
WTH	1	16	13	477	0.027	0.02948	0.00087
AMCH	1	2	2	70	0.029	0.02816	0.00079
AMCH	1	2	2	48	0.042	0.01516	0.00023
AMCH	1	3	9	168	0.054	0.00316	1E-05
AMCH	1	3	1	18	0.057	-8.2E-05	6.8E-09
AMCH	1	5	8	183	0.044	0.01302	0.00017
AMCH	1	8	18	428	0.042	0.01467	0.00022
AMCH	1	6	9	181	0.050	0.00701	4.9E-05
AMCH	1	9	26	284	0.092	-0.03481	0.00121
AMCH	1	4	29	446	0.065	-0.00829	6.9E-05
AMH	1	7	11	130	0.085	-0.02788	0.00078
AMH	1	5	5	194	0.026	0.03096	0.00096
AMH	1	6	8	320	0.025	0.03174	0.00101
AMH	1	12	19	542	0.035	0.02168	0.00047
AMH	1	1	130	2044	0.064	-0.00687	4.7E-05
AMH	1	11	5	221	0.023	0.03411	0.00116
RNZ	1	11	7	227	0.031	0.0259	0.00067
RNZ	1	11	15	357	0.042	0.0147	0.00022
RNZ	1	11	13	370	0.035	0.0216	0.00047
RNZ	1	10	23	1235	0.019	0.03811	0.00145
RNZ	1	8	102	1312	0.078	-0.02101	0.00044
RNZ	1	7	71	1000	0.071	-0.01426	0.0002
RNZ	1	6	104	1312	0.079	-0.02253	0.00051
RNZ	1	5	115	1312	0.088	-0.03092	0.00096
RNZ	1	0	7	274	0.026	0.03116	0.00097
RNZ	1	1	30	497	0.060	-0.00363	1.3E-05
sum of n =	27		787	13871	0.057		0.01511
			total occupancy	total area	(Mean)	variance =	0.00056
						SD =	0.024
						3*SD =	0.071
					standard error of the mean =		0.005
					ie the mean is within	0.043	to 0.070

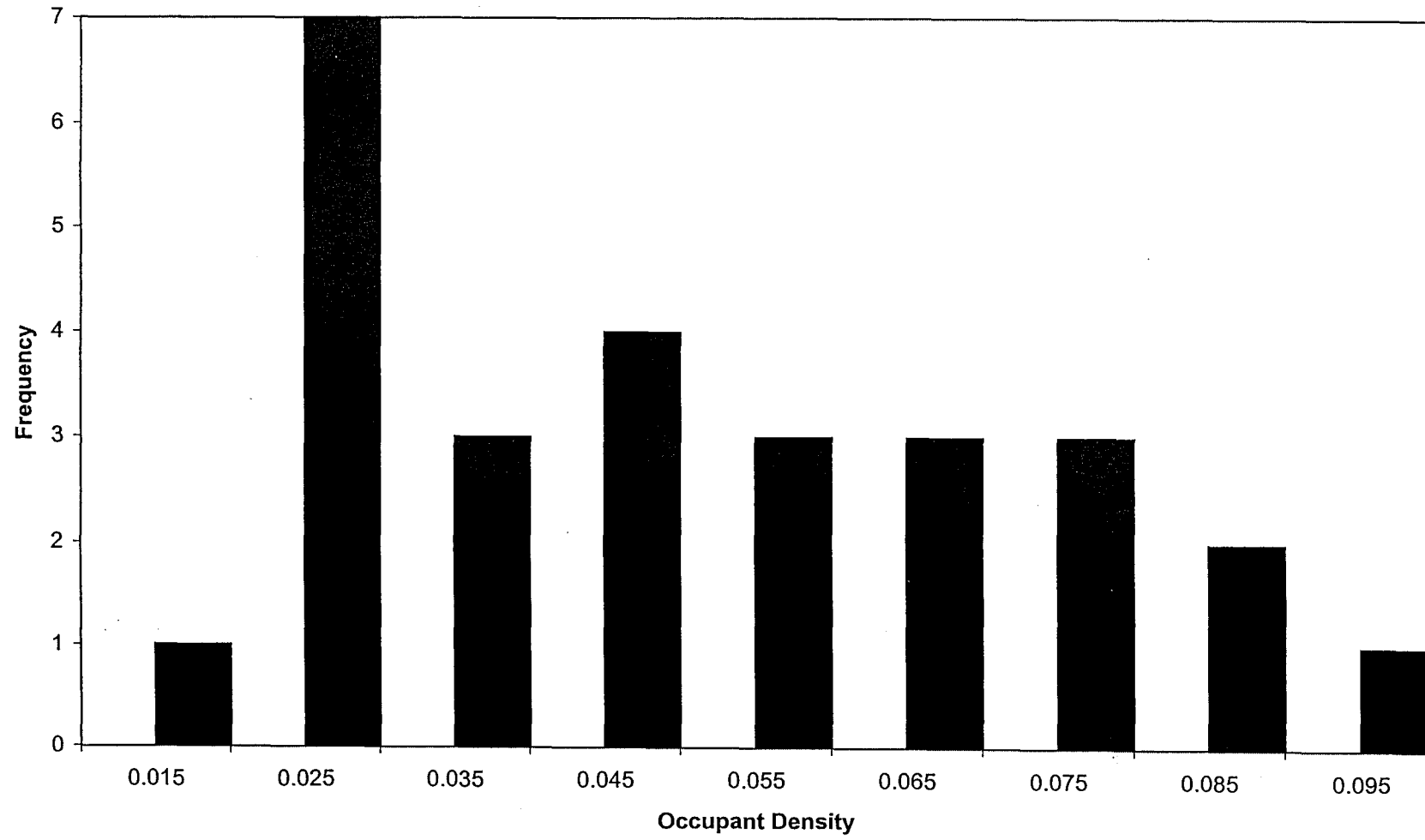
Now to consider **density vs area**

BUILDING	n	floor	No occupants	Area m ²	density p/m ²
RNZ	1	10	23	1235	0.019
WTH	1	8	5	222	0.023
AMH	1	11	5	221	0.023
AMH	1	6	8	320	0.025
RNZ	1	0	7	274	0.026
AMH	1	5	5	194	0.026
WTH	1	16	13	477	0.027
AMCH	1	2	2	70	0.029
RNZ	1	11	7	227	0.031
AMH	1	12	19	542	0.035
RNZ	1	11	13	370	0.035
AMCH	1	2	2	48	0.042
RNZ	1	11	15	357	0.042
AMCH	1	8	18	428	0.042
AMCH	1	5	8	183	0.044
AMCH	1	6	9	181	0.050
AMCH	1	3	9	168	0.054
AMCH	1	3	1	18	0.057
RNZ	1	1	30	497	0.060
AMH	1	1	130	2044	0.064
AMCH	1	4	29	446	0.065
RNZ	1	7	71	1000	0.071
RNZ	1	8	102	1312	0.078
RNZ	1	6	104	1312	0.079
AMH	1	7	11	130	0.085
RNZ	1	5	115	1312	0.088
AMCH	1	9	26	284	0.092
sum of n =	27		787 total occupancy	13871 total area	0.057 (Mean)

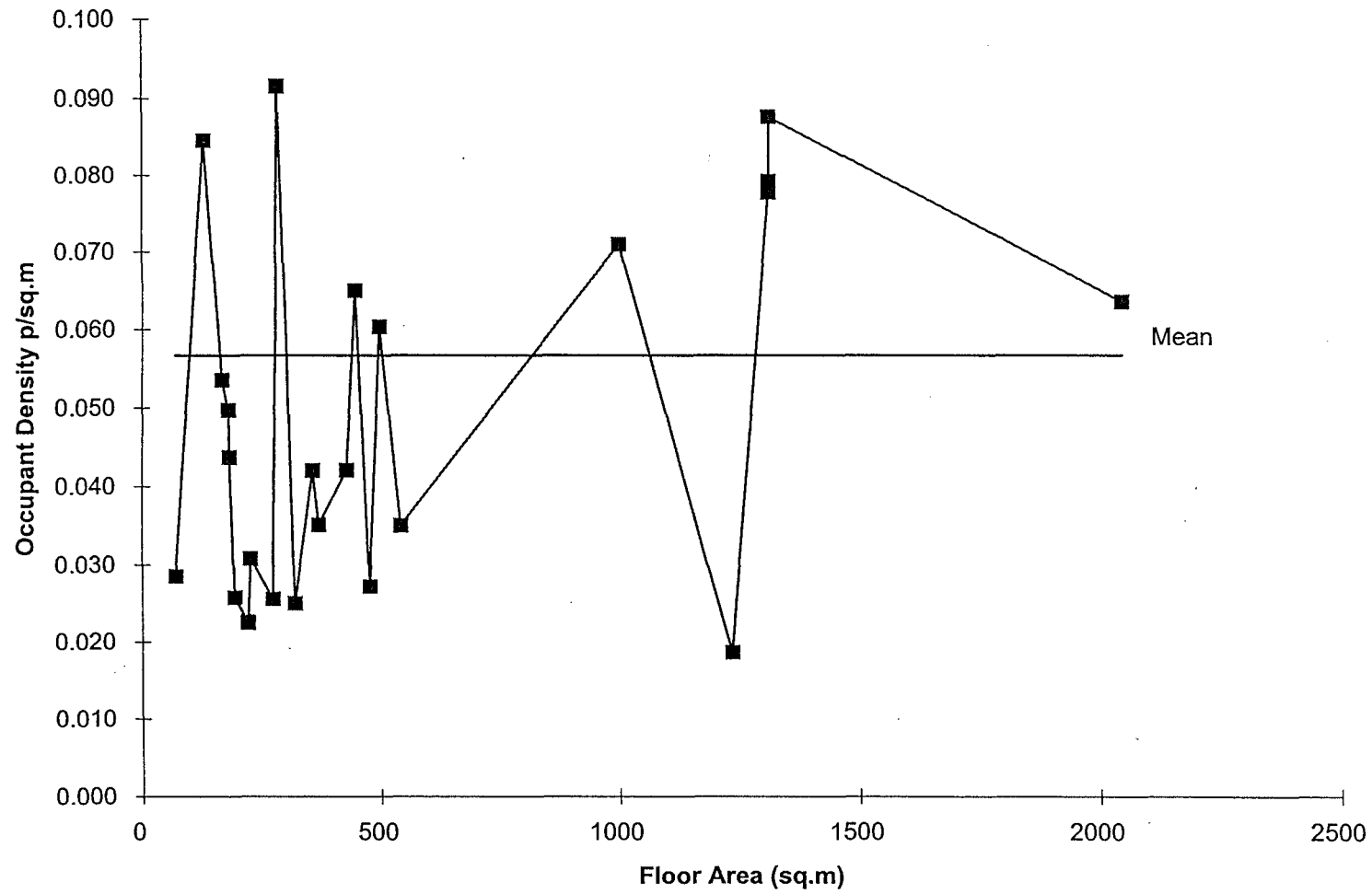
Checking now on the frquencies of different occupancy bands

Band from	to	midrange	frequency
0.01	0.0195	0.015	1
0.02	0.0295	0.025	7
0.03	0.0395	0.035	3
0.04	0.0495	0.045	4
0.05	0.0595	0.055	3
0.06	0.0695	0.065	3
0.07	0.0795	0.075	3
0.08	0.0895	0.085	2
0.09	0.0995	0.095	1
total =			27

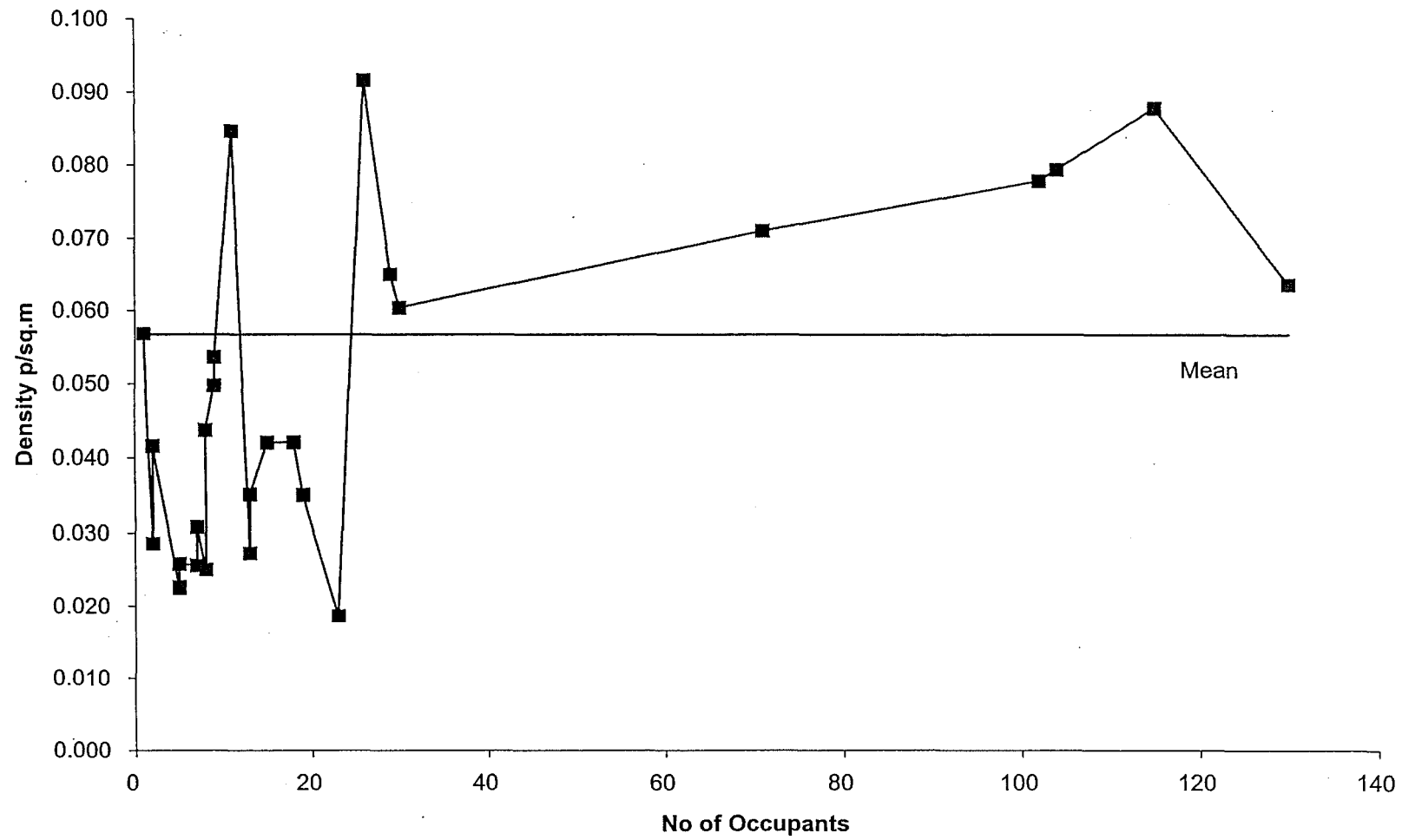
Frequency vs Occupant density



Occupant Density vs Floor Area



Occupant Density vs No of Occupants



Building Name:
Address (street, no.):

BUILDING OCCUPANCY SURVEY
for
DESIGN FOR MEANS OF ESCAPE FOR FIRE SAFETY

This survey is part of a study of Means of Escape for Fire Safety and aims to determine the actual occupant density (in persons/square metre of floor area) present during normal business hours over all the floors of this building. .

Response of one form is requested from each business/tenant for each floor (or part floor) occupied by the business.

Business name: being sole business on this floor Y/N
being one of..... businesses on this floor

Floor: (circle one) LG G 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Rentable floor area of this tenancy:sq.feet/sq. m
and includes for our sole use - toilet area(s) Y/N
lift lobby(s) Y/N
kitchen(s) Y/N

Our full complement of staff, general activity and the areas allotted (if possible) are as follows:

General business activity - Medical rooms Legal offices Insurance
Architects/engineers Accounting Real Estate Computer programmers
Other (indicate).....

Occupancy activity	Numbers (persons)	Floor area (gross)	Occupancy activity	Numbers (persons)	Floor area (gross)
Waiting area	Open offices	.....	.....
Front desk/ receptionists	Ind'l offices	.....	.....
Gen'l storage	Files	.....	.....
			Other	.....	.....

Please answer as many of the questions as possible If you would like assistance in the completion of this form please contact the author at the contact number below. If you have completed it unassisted thank you for the time and effort.

Please return by **1 February** to- Ian J Garrett, PO Box 588, Wellington
2370648 (ph); 4712372 (fax); or ijg@spencerholmes.co.nz

APPENDIX C

EGRESS CALCULATIONS - WORKED EXAMPLE

EGRESS CALCULATIONS

Considering an example problem - 11 storey building, with 20 persons /floor with a single means of escape, except that Ground level has separate egress.

Each floor is 10m x 20m of net 'office' area. The exit dooors are all 1m wide, and the stair are 1200mm wide. The goings and risers are 280mm and 180mm respectively.

From FEDG table 9.1 -

for flow on horizontal - $F_{sm} = 78 \text{ p/min.m}$
and on stairs = 60 p/min.m

Starting at level 11 (ie 10th floor)

Input values marked ****

Floor area = $10 \text{ m} \times 20 \text{ m} = 200 \text{ Af m}^2$
travel distance to doorway/stairs $L1 = 25 \text{ m}$ ****
Population density for occupancy WL = 0.1 D1 p/m^2
For calculations density Do, is to be ≥ 0.5 , $Do = 0.5 \text{ Do p/m}^2$
Total population on floor = $Af \cdot D1 = No = 20 \text{ persons}$
For a flat floor/corridor $kt = 84$
 $S = kt \cdot (1 - 0.266Do) = 72.83 \text{ m/min}$
 $tr1 = \text{traverse time for } L1 = L1/S = 0.34 \text{ min}$

Now access width into stairs, width = $W = 1 \text{ m}$ ****
boundary width $B = 0.15 \text{ m}$ ****
effective width $We = W - 2 \cdot B = 0.7 \text{ m}$
 $F_s = \text{specific flow thro doorway} = S \cdot Do = 36.41 \text{ p/min.m}$
 $F_c = \text{actual flow thro doorway} = F_s \cdot We = 25 \text{ p/min}$
 $tr2 = \text{time to travel thro doorway} = No/F_c = 0.78 \text{ min}$

So travel through the doorway controls at each floor.

and will result in queuing at each level.

For the flow down the stairs

Now actual width of stairs, width =	$W = 1.2$	m	****
boundary width $B =$	0.15	m	****
effective width $We = W - 2*B =$	0.9	m	
Stairs going dimension $= G =$	0.28	m	****
Stairs riser dimension $= R =$	0.18	m	****
Stair slope - (R/G)	0.6429		
Stair slope $= \tan^{-1}(R/G)$	$= \theta$	0.5713	rad
Interstorey height $H_t =$	3	m	*****
Stair length, on slope $= L_s = 2 + H_t/\sin(\theta)$	7.55	m	(incl 1m landing)
For stairs, $k_t = 51.8*(G/R)^{0.5} =$	64.61		

Using the actual flow of people as they pass thro the doorway above,
and the width of the space (stairs) they enter

$F_s = \text{specific flow} = F_c / We =$	28.32	p/min.m
---	---------	---------

For a single stair this cannot be more than the flow at the doorway
above ie = 36.41

So use $F_s = 28.32$ p/min.m

Relating $S = k_t(1 - 0.266*D_s)$ and $F_s = S*D_s$

So $F_s = k_t(1 - 0.266*D_s)*D_s$

we end up with a standard quadratic eqn for D_s where -

$a = 0.266*k_t =$	17.19
$b = -k_t =$	28.32

So $D_s = 3.25$ or 0.51 persons/m²

travel speed on stairs $= S = k_t(1 - 0.266*D_s) =$

8.71 or 55.90	m/min
-------------------	-------

So, $t_{rs} = \text{time to travel down stairs} = L_s / S =$

0.87 or 0.14	min
------------------	-----

Using D_s closest to original ($D_o =$

0.5) $t_r =$	0.14	min	****
$=$	8	seconds	

Now at level 10 the descending stair meets up with the occupants of this level

(assuming they all start at the same time)

We need to estimate the resulting F_c

$$\begin{aligned}
 F_c &= \{[F_{c1} \cdot W_{e1}] + [F_{c2} \cdot W_{e2}]\} / W_{eout} \\
 &= (25 \cdot 0.9 + 25 \cdot 0.7) / 0.9 \\
 &= 45.32 \text{ p/min}
 \end{aligned}$$

So $F_s = 45.32 \cdot 0.9 = 40.78 \text{ p/min.m}$

This is less than F_{sm} , So use $F_s = 40.78 \text{ p/min.m}$

Relating $S = k_t(1 - 0.266 \cdot D_s)$ and $F_s = S \cdot D_s$

$$\text{So } F_s = k_t(1 - 0.266 D_s) \cdot D_s$$

we end up with a standard quadratic eqn for D_s where -

$$a = 0.266 \cdot k_t = 17.19$$

$$b = -k_t = -64.61$$

$$c = F_s = 40.78$$

$$\text{So } D_s = 2.96 \text{ or } 0.80 \text{ persons/m}^2$$

travel speed on stairs $= S = k_t(1 - 0.266 D_s) =$

$$13.79 \text{ or } 50.81 \text{ m/min}$$

So, $t_{rs} = \text{time to travel down stairs} = L_s / S =$

$$0.55 \text{ or } 0.15 \text{ min}$$

Using D_s closest to original ($D_o =$

$$0.5) \quad t_r = 0.15 \text{ min} \quad \text{****}$$

$$= 9 \text{ seconds}$$

Level 9

So at the next level, stairs $F_{c1} = F_s \cdot W_e = 40.78 \cdot 0.9$

$$36.71 \text{ p/min}$$

$$\text{floor } F_{c2} = F_c = 25.49 \text{ p/min}$$

We need to estimate the resulting F_c

$$\begin{aligned}
 F_c &= \{[F_{c1} \cdot W_{e1}] + [F_{c2} \cdot W_{e2}]\} / W_{eout} \\
 &= 56.53 \text{ p/min}
 \end{aligned}$$

So $F_s = 50.88 \text{ p/min.m}$

This is less than F_{sm} , So use $F_s = 50.88 \text{ p/min.m}$

Relating $S = k_t(1 - 0.266 \cdot D_s)$ and $F_s = S \cdot D_s$

$$\text{So } F_s = k t (1 - 0.266 D_s) D_s$$

we end up with a standard quadratic eqn for D_s where -

$$a = 0.266 k t = 17.19$$

$$b = -k t = -64.61$$

$$c = F_s = 50.88$$

$$\text{So } D_s = 2.64 \quad \text{or} \quad 1.12 \quad \text{persons/m}^2$$

$$\text{travel speed on stairs} = S = k t (1 - 0.266 D_s) =$$

$$19.30 \quad \text{or} \quad 45.31 \quad \text{m/min}$$

$$\text{So, } t_{rs} = \text{time to travel down stairs} = L_s / S =$$

$$0.39 \quad \text{or} \quad 0.17 \quad \text{min}$$

Using D_s closest to original ($D_o =$

$$3) \quad t_r = 0.17 \quad \text{min} \quad \text{****}$$

$$= 10 \quad \text{seconds}$$

Level 8

$$\text{So at the next level, stairs } F_{c1} = F_s \cdot W_e = 45.79 \quad \text{p/min}$$

$$\text{floor } F_{c2} = 25.49 \quad \text{p/min}$$

We need to estimate the resulting F_c

$$F_c = \{ [F_{c1} \cdot W_{e1}] + [F_{c2} \cdot W_{e2}] \} / W_{eout}$$

$$= 65.62 \quad \text{p/min}$$

$$\text{So } F_s = 59.05 \quad \text{p/min.m}$$

This is less than F_{sm} ,

$$\text{So use } F_s = 59.05 \quad \text{p/min.m}$$

$$\text{Relating } S = k t (1 - 0.266 D_s)$$

$$\text{and } F_s = S \cdot D_s$$

$$\text{So } F_s = k t (1 - 0.266 D_s) D_s$$

we end up with a standard quadratic eqn for D_s where -

$$a = 0.266 k t = 17.19$$

$$b = -k t = -64.61$$

$$c = F_s = 59.05$$

$$\text{So } D_s = 2.19 \quad \text{or} \quad 1.57 \quad \text{persons/m}^2$$

$$\text{travel speed on stairs} = S = k t (1 - 0.266 D_s) =$$

$$26.95 \quad \text{or} \quad 37.65 \quad \text{m/min}$$

$$\text{So, } t_{rs} = \text{time to travel down stairs} = L_s / S =$$

$$0.28 \quad \text{or} \quad 0.20 \quad \text{min}$$

Using D_s closest to original ($D_o =$

$$0 \quad) \quad tr = 0.20 \quad \text{min}$$

$$= 12 \quad \text{seconds}$$

Level 7

So at the next level, stairs $F_{c1} = F_s \cdot W_e = 53.15 \quad \text{p/min}$

floor $F_{c2} = 25.49 \quad \text{p/min}$

We need to estimate the resulting F_c

$$F_c = \{[F_{c1} \cdot W_{e1}] + [F_{c2} \cdot W_{e2}]\} / W_{eout}$$

$$= 72.97 \quad \text{p/min}$$

$$\text{So } F_s = 65.68 \quad \text{p/min.m}$$

This is greater than F_{sm} , " So use $F_s = 60.00 \quad \text{p/min.m}$

Relating $S = k_t \cdot (1 - 0.266 \cdot D_s)$ and $F_s = S \cdot D_s$

$$\text{So } F_s = k_t \cdot (1 - 0.266 D_s) \cdot D_s$$

we end up with a standard quadratic eqn for D_s where -

$$a = 0.266 \cdot k_t = 17.19$$

$$b = -k_t = -64.61$$

$$c = F_s = 60.00$$

$$\text{So } D_s = 2.08 \quad \text{or} \quad 1.68 \quad \text{persons/m}^2$$

travel speed on stairs $= S = k_t \cdot (1 - 0.266 D_s) =$

$$16.35 \quad \text{or} \quad 20.35 \quad \text{m/min}$$

So, $tr_s = \text{time to travel down stairs} = L_s / S =$

$$0.46 \quad \text{or} \quad 0.37 \quad \text{min}$$

Using D_s closest to original ($D_o =$

$$9 \quad) \quad tr = 0.37 \quad \text{min} \quad \text{****}$$

$$= 22 \quad \text{seconds}$$

This will apply for all floors from here down

The travel time to the exit at ground floor is as for travel at each

$$\text{other floor} = 0.34 \quad \text{min}$$

If it is assumed that the time to validate the alarm is - $0.5 \quad \text{min}$

And the time to respond to move - $0.5 \quad \text{min}$

$$\text{total delay, no FoS} = 1.34 \quad \text{min}$$

	time from alarm no FoS		
At tm time, 1st persons leave the first flight =	0.14	min	1.48
Occupants leaving the stairway is =	4	persons	
Balance remaining to escape =	196	persons	
The next group require	0.15	min	1.63
the travel rate is	45.32	p/min	
Occupants leaving the stairway is =	7	persons	
Balance remaining to escape =	189	persons	
The next group require	0.17	min	1.80
the travel rate is	56.53	p/min	
Occupants leaving the stairway is =	10	persons	
Balance remaining to escape =	180	persons	
The next group require	0.2	min	2.00
the travel rate is	65.62	p/min	
Occupants leaving the stairway is =	13	persons	
Balance remaining to escape =	166	persons	
The balance escape at	54.00	p/min	
The time required is	3.08	min	5.08
Total stair travel time =	3.74	min	5.08

Above it was assumed that the time to validate the alarm is -	0.5	min
And the time to respond to move -	0.5	min
"Apply a factor of safety of 2 to these, ie an extra margin of"	1	min
Gives a total time from alarm of =	6.08	min

It is assumed that the flow on the stairs from above takes precedence, and there is no margin given -

This means that the last person will vacate the 1st floor (level 2) at -

	5.08	
flow time on last storey of stairs	-0.20	
flow time to ground exit	<u>-0.34</u>	
	4.94	min

Consider now a Moderate fire on level 2 with sprinkler/heat detectors

and smoke detectors. the alarms can be assumed to be activated instantaneously.

From FPETool -

Smoke detectors will operate at -	1.52	min
Smoke will be down to head level at -	3.00	min
(and visibility in layer is less than 6m)		
Heat/Sprinklers will operate at -	3.52	min
CO2 will be untenable (no sprinklers) at -	3.93	min

Consider now time line - from commencement of fire (with no safety factors):

Time (min)	Smoke Detector system	Heat detector System
0		
1.5	Detector activates alarm	
1.6		
1.7		
1.8		
1.9		
2	Complete investigation	Assume smoke cue alarms
2.1		
2.2		
2.3		
2.4		
2.5	Complete pack - up	Complete investigation
2.6	first storey travelled	
2.7		
2.8		
2.9	first person leaves building	
3		Complete pack - up
3.1	Smoke at head level on fire floor	first storey travelled
3.2		

3.3		
3.4		first person leaves building
3.5		Heat detector operates
3.6		(Sprinkler will reduce fire effect)
3.7		
3.8		
3.9	CO2 @ serious level	
4		
4.1		
4.2		
4.3		
4.4		
4.5		
4.6		
4.7		
4.8		
4.9		
5		
5.1		
5.2		
5.3		
5.4		
5.5		
5.6		
5.7		
5.8		
5.9		
6		
6.1		
6.2		
6.3		
6.4		
6.5		
6.6	last person leaves	
6.7		
6.8		
6.9		
7		
7.1		last person leaves
7.2		
7.3		
7.4		
7.5		

Even with sprinklers, and no safety factors, occupants of the fire floor are at serious risk because the floor will not be vacated by the time the sprinklers are activated.

Comparing these results with Pauls (1995) times for tall buildings with

$$\begin{aligned}
 N &= 200 \text{ persons} \\
 W_e &= 0.9 \text{ m on the stairs} \\
 t_{ev} &= 0.68 + 0.081 * ((200/0.9)^{0.73}) \\
 &= 4.86 \text{ minutes from the time of alarm.}
 \end{aligned}$$

For smoke detector activation (as above) this gives 6.4 minutes, and for a smoke cue - 6.9 minutes for time for evacuation from the commencement of the fire. These times should be compared with the 6.6 and 7.0 minutes respectively from the spreadsheet.

APPENDIX D

OCCUPANT DENSITIES

Occupant Densities

(BIA (1995) Table A2)

Activity on any floor or firecell	Occupant density (Users per m ²)
Crowd Activities	
Standing Space	2.6
Bar standing areas	2.0
Stadia and grandstands	1.8
Space with fixed seating	as number of seats (see Note 1)
Space with loose seating	1.3
Areas without seating or aisles	1.0
Exhibition areas, trade fairs	0.7
Concourses, lobbies and foyers	1.0
Bar seating areas	1.0
Dance floors	1.7
Stages for theatrical performances	1.3
Spaces with loose seating and tables	0.9
Restaurants, dining rooms	0.9
Dining, beverage and cafeteria spaces	0.8
Indoor games areas/bowling alleys etc	0.1
Classrooms	0.5
Reading or writing rooms and lounges	0.5
Teaching laboratories	0.2
Vocational training rooms in schools	0.1
Gymnasias	1.7
Supermarkets, bazaar shops	0.5
Sales floor, ground and basement	0.4
Sales floor, upper floors	0.2
Showrooms	0.2
Sleeping Activities	
Bunkrooms	as number of
Bedrooms	bedspaces
Dormitories, hostels	(See Note 1)
Detention quarters	
Wards containing more than 2 beds	
Working business and storage activities	
Reception areas	0.1
Interview rooms	0.2
Personal service facilities	0.2
Offices and staffrooms	0.1
Computer rooms	0.04
Workrooms, workshops	0.2
Manufacturing and process areas, staff rooms	0.1
Kitchens	0.1
Commercial laboratories, laundries	0.1
Warehouse storage	0.03
Heavy industry	0.03
Aircraft hangars	0.02
Bulk storage	0.01
Parking buildings, garages	0.02
Factory space in which layout and normal use of fixed equipment or plant determines the number of persons using it in working hours	as approved (See Note 2)

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